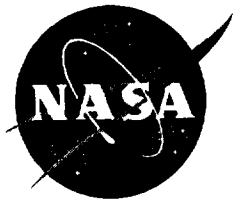


NASA/CR—2001–210920



# Evaluation of a Terminal Area In-Trail Approach Spacing, Project and Study

Stephen Shelden  
San Jose State University, NASA Ames Research Center, Moffett Field, CA

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April 2001

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Prepared for NASA Ames Research Center  
under Contract NCC 2-1095

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April 2001

### **Acknowledgments**

The author would like to acknowledge the assistance of those Raytheon Corporation individuals who prepared the simulation environment, San Jose State University Foundation and NASA Ames Research Center for funding, and Dr. Walter Johnson for technical and editorial assistance in preparing this document.

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## **List of Abbreviations**

ADS-B	Automatic Dependent Surveillance – Broadcast
AATT	Advanced Air Transportation Technologies
ATC	Air Traffic Control (Controller)
CDTI	Cockpit Display of Traffic Information
CE11	Concept Element 11
DAG-TM	Distributed Air / Ground – Traffic Management
DST	Decision Support Tool
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
NAS	National Air Space
NASA	National Aeronautics and Space Administration
STAR	Standard Terminal Arrival Route
TCAS	Traffic Collision Avoidance System
TRACON	Terminal Radar Approach Control
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions



## **Executive Summary**

Reported here are the results of work completed as a precursor to Distributed Air Ground (DAG), Concept Element 11 (CE11) research. CE11 is a NASA, Advanced Air Transportation Technologies (AATT) concept initiated to promote research on in-trail merging and spacing during approach in the terminal area environment, such that improvements to the National Air Space (NAS) may be realized.

A description of the project concept, results of a preliminary study, and a literature review are presented. In terms of conclusions, study results, and reference material respectively:

- the concept is supported as being significant to NAS capacity improvement
- the preliminary study indicated that having more than one downstream, in-trail aircraft present on a CDTI during approach may be advantageous, and that flying traditional Standard Terminal Arrival Routes (STAR) utilizing advanced decision support tools (DST) may be complicated by wake turbulence considerations, a lack of vertical awareness on the part of the flight crew, and the 'step-down' nature of many terminal area approaches
- the results of a literature review are presented for future reference.

## **Introduction**

Airport inbound capacity – an airport’s ability to accept arriving aircraft – is typically expressed as a number per hour, and is based on 1) the number and configuration of available runways, and 2) optimal flight operations under Visual Meteorological Conditions (VMC).

At San Francisco International (SFO) airport, maximum arrival acceptance capacity is approximately 60 aircraft per hour with multiple runways available and in use. In other than VMC – at SFO being a ceiling and visibility less than 5000 feet and 5 miles respectively – utilization of the available capacity to accept arriving aircraft falls away quickly. In addition to the cessation of parallel approaches under IMC (Instrument Meteorological Conditions), SFO capacity is also affected by the curtailment of approaches where the controller is otherwise able to hand off separation maintenance to the flight deck – where flight crews report the lead “aircraft in sight” and are cleared for a visual approach.

Citing from Reference 1, “visual approaches are the backbone of operations at major airports in the U.S. When visual approaches cannot be conducted, a significant loss in airport capacity often results. For example, the capacity at Boston Logan may decrease from 60 during visual approaches, to 34 in a single runway operation.”

In its simplest terms, two main factors influence airport arrival capacity utilization under IMC, 1) weather, and 2) the limited operational capabilities of the controlling Terminal Radar Approach Control (TRACON) facility.

Weather can hamper operations both in the air and on the ground. In the air, re-routing to an alternate runway or destination airport may be necessary due to changing local conditions or substantial weather events. On the ground, increased braking distance and the resulting speed with which aircraft can clear active runways may be affected, and poor visibility may restrict taxiway navigation and speed to and from terminal gates.

At the TRACON, IMC precludes the use of visual approaches, most significantly, those where separation assurance is handed-off to aircraft in-trail on approach. Consequently, Air Traffic Controllers (ATCs) increase aircraft separation above the required minimum – the exact distance predicated in part on the individual controller – to accommodate the limited accuracy of facility equipment and surveillance data. These spacing “buffers” that TRACON controllers routinely implement under IMC are further described in the next section.

The Distributed Air/Ground – Traffic Management (DAG-TM), Concept Element 11 (CE11) work described below is an effort directed toward determining if the spacing buffers can be reduced, and whether

advanced displays and procedure changes can be safely implemented to improve airport arrival capacity under non-VFR conditions.

In the course of preparing for CE11-based research, a literature review going back two decades was undertaken. The citations are presented in Appendix A, sorted alphabetically by paper title, with either the attendant abstract or a brief summary of the research.

## Concept Element 11

### Background

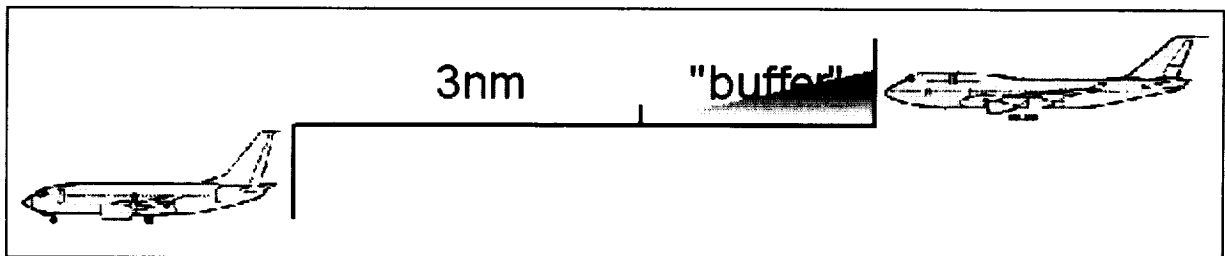
The NASA Distributed Air/Ground – Traffic Management program is a set of conceptual elements that describe possible modes of operation within the outlines of the Free Flight concept defined by RTCA Task Force 3. The DAG-TM vision (see Reference 2) is described as, "... a National Airspace System concept in which flight deck (FD) crews, air traffic service providers (ATSP) and aeronautical operational control (AOC) facilities use distributed decision-making to... increase system capacity. DAG-TM will be accomplished with a human-centered operational paradigm enabled by procedural and technological innovations."

### Concept Description

Concept Element 11 is described in the DAG-TM proposal (Reference 2) as addressing how: "Excessive in-trail spacing buffers in arrival streams reduce runway throughput and airport capacity, especially in conditions of poor visibility and/or low ceilings."

In terminal area environments operating under IMC, utilization of airport arrival capacity routinely falls well below the VMC maximum possible. While the effects of weather on more than simply visibility aloft are frequently responsible for this under-utilization, it is also the case that poor visibility alone forces TRACON controllers to apply in-trail spacing buffers to arrival streams in order to guarantee minimum separation requirements between successive aircraft are met. The resulting generous in-trail arrival spacing – the "buffers" referred to above, see Figure 1 – can reduce runway throughput below the airport facility's actual capacity to accept arriving aircraft.

**Figure 1.** TRACON controlled in-trail spacing, illustrating the IMC "buffer."



### Proposed Solution

In broad terms, the CE11 solution is for appropriately equipped aircraft to be given clearance to merge with an arrival stream, and/or maintain in-trail separation relative to a leading aircraft. Taken directly from the DAG-TM

proposal: "Self spacing will enable the FD to autonomously merge with another arrival stream and/or maintain in-trail separation relative to another aircraft under IMC as they would under VMC, thus significantly increasing arrival throughput."

### **Concept Validity**

As a concept, CE11 is well supported by the existing literature as a research effort that could realize a significant capacity increase in the NAS. Illustrating this:

- In 1980, Harris delivered an AIAA paper on "technological approaches and operational procedures currently under development by the FAA to increase airport capacities and efficiencies." Among those technologies and procedures was an effort to deliver "reductions in IFR final approach spacing." (Reference 3)
- Williams (1983) speculated the CDTI to be an extension of the pilots' visual separation responsibility to non-visual electronic separation tasks, citing decreased ground controller workload and increased airport capacity as potential benefits. (Reference 4)
- In 1992, Sorensen pointed out that "significant runway throughput is lost due to ineffective control of aircraft spacing during final approach." (Reference 5)
- Johnson (1996) observed that "while much of the emphasis of the free-flight movement has been concentrated on reducing enroute delays, airport capacity is a major bottleneck in the current airspace system, particularly during bad weather. (Reference 6)
- Quoting from the results of Ballin and Erzberger (1996) "a large potential existed to reduce the controller separation buffer through increased spacing precision, especially for lead/trail combinations." (Reference 7)
- With visual approaches being "the backbone of operations at major airports in the U.S.," significant airport capacity goes un-utilized in conditions other than VMC. Mundra, 1997. (Reference 1)
- In 1997, Corwin observed that "an ongoing source of airspace inefficiency are takeoff and landing operations at hub airports when other than VFR, 'see and avoid,' conditions exist. What is required to keep airspace capacity operating in a robust manner is to provide pilots some alternative means to 'see and avoid' during IFR conditions so that airport arrival rates are maintained." (Reference 8)
- Of perhaps greater import to the global issue of free flight and NAS capacity, Corwin further observed that "aircraft are not sequenced a specific number of miles-in-trail so the enroute, high and super high altitude controllers can handle the workload, rather the miles-in-trail artifact is so that aircraft arriving into the terminal area

can be accommodated without undo vectoring and holding. The influence of the overburdened TRACON system... forces aircraft to fly in a lock-step manner. What's required for improving airspace efficiency is some form of capacity improvement in the terminal area." (Reference 8)

- In summary, "a primary impediment to aircraft traffic flow is the loss of available throughput of the runways and terminal airspace at the nation's major airports. A significant amount of the throughput loss is due to ineffective scheduling and controlling of aircraft in the approach and landing process. This inefficiency is due to the spatial gaps between sequential landing aircraft being greater than required for flight safety. The flight safety requirements are defined by wake vortex separation constraints and runway occupancy time requirements. The throughput loss due to the spacing inefficiency has been estimated to be as high as 25 percent during Instrument Meteorological Conditions." (Reference 5)

#### **Potential Benefits**

Proceeding with CE11, researching and refining the automation needed, designing and testing decision support tools (DSTs), and developing new operational procedures could have a demonstrable effect in terms of realizing NAS improvements. In conclusion, CE11 would:

- make for improved use of airport capacity, allowing for a facility's existing maximum arrival capacity to be utilized under a broader range of weather conditions, without compromising safety or existing separation standards
- reduce the pressure for large (and usually controversial) infrastructure projects designed to accommodate increased traffic, by instead maximizing existing facility capacity
- complement ground technologies such as CTAS and FAST
- lessen TRACON controller workload by distributing, sharing, and/or transferring procedures and responsibilities to flight crew
- be a logical extension of enroute free flight, and
- attack the NAS capacity problem at one of the clearly identified choke points

## Spacing Study

### Introduction

Goal one of the study was to determine whether approach spacing relative to a lead aircraft, when supported by a CDTI, was enhanced by the presence of additional down-stream, in-trail aircraft. Goal two was to accumulate baseline data for future CE11 work, and to gather pilot insight into CDTI-based in-trail spacing on approach.

### Method

*Participants* – Eight commercial passenger pilots were recruited to take part in the study. Six Captains and two First Officers participated. Average age was 44.5 years. Selected demographics are presented in Table 1. Each participant was compensated for his or her time.

**Table 1.** Selected demographics and ratings of study participants.

<b>Demographic (n = 8)</b>			
Mean number of years flying	26.8 yrs	TCAS used for overall traffic awareness:	
Mean number hrs flown last 12 months	626.3 hrs		Never 0
Mean "Glass" hrs flown past 12 months	582.5 hrs		Not very often 0
Previous military experience	5		Often 2
Subjective TCAS experience rating:		Very often 1	
		All the time 5	
		TCAS used to identify a specific aircraft:	
	Never used / Not required 0		Never 0
	Never used, but operation understood 0		Not very often 1
	Used, but minimal familiarity 0		Often 2
	Average 6		Very often 1
Above Average 2			All the time 4

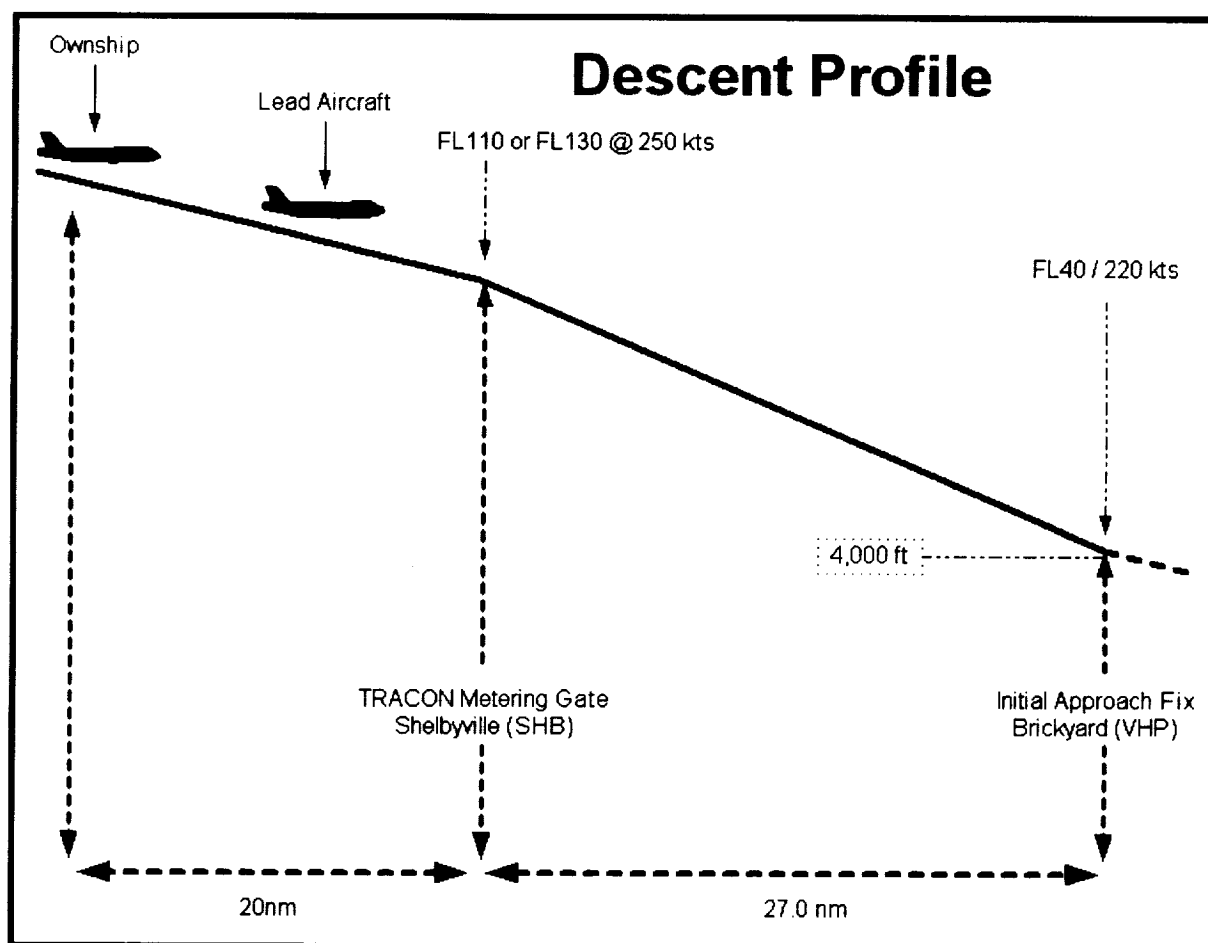
Asked whether they had "unofficially" used TCAS to maintain in-trail separation, five participants responded that they had. Under exactly what circumstances is referenced in the discussion section.

*Procedure* – Pilot participants were asked to "fly" arrival segments in a mid-fidelity simulator (see miniACFS described below), using a CDTI (described below) for in-trail spacing, set to display a range of 10nm. In condition 1, participants were asked to fly an "optimal" approach with no lead aircraft present, and hence, no in-trail spacing target. In conditions 2 and 3, with one and two downstream CDTI aircraft present respectively, participant's

began 5nm behind the proximal lead aircraft, and were asked to close (“safely but expeditiously”) and maintain 3nm astern for the duration of the approach. The lead aircraft in all cases mirrored the operating characteristics of a Boeing 737-200 aircraft, and met all required STAR restrictions.

All trials begin 20nm from the terminal metering gate, and ended at the initial approach fix (see Figure 2). The descent profiles flown were either shallow or steep. A shallow descent trial began at an altitude of 16,000 feet, and required that ownship cross an initial waypoint (SHB) at 11,000 feet, and a subsequent waypoint (VHP) at 4,000 feet. A steep descent trial began at 18,000 feet, and required ownship cross an initial waypoint (SHB) at 13,000 feet, and a subsequent waypoint (VHP) at 4,000 feet. An example of a steep descent STAR chart from the study is shown below, see Figure 3. In all other respects each of the trials were identical.

**Figure 2.** Descent profile used in study.





FOR SIMULATION ONLY -- NOT FOR NAVIGATION

**Initialization**

18000 FT / 250 KIAS / SHB 297 (HDG / Course) / 20 NM

**TASK**

Comply with HOMER1 Arrival.

C2-r

**Clearance**

NASA 1, in-trail separation procedures in effect, close and maintain 3 NM behind United Airlines 1018, cross Shelbyville (SHB) at one three thousand (13000'), cross Brickyard (VHP) at four thousand (4000') and 220 kts. Report identification of United 1018.

**STAR**

Simulation 27 NOV 99

XX - 2A

Eff 3 Dec

INDIANAPOLIS, IND

INDIANAPOLIS INTL D-ATIS 124.4

INDIANAPOLIS INTL

**HOMER ONE (HOMER.HOMER1)**

**VERTICAL NAVIGATION PLANNING INFORMATION**

All aircraft: Expect to cross SHB at 11000' or 13000'.

**ARRIVAL**

From over SHB VOR fly VHP R-117, cross VHP VOR at 4,000' at 220 kts.

The diagram shows the flight path from the start of the arrival sequence to the final destination, Indianapolis International Airport (IND). The path consists of several segments:

- Start Point:** A triangle symbol representing the start of the arrival sequence.
- Segment 1:** A heading of 297° leads to the **SHELBYVILLE VOR** station. The frequency is 112.0 MHz (SHB), and coordinates are N39 38.0 W085 49.5.
- Segment 2:** From SHELBYVILLE VOR, a heading of 297° leads to the **BRICKYARD VOR** station. The frequency is 116.3 MHz (VHP), and coordinates are N39 48.9 W086 22.1.
- Segment 3:** From BRICKYARD VOR, a heading of 297° leads to the **Indianapolis VOR** station. The frequency is 118.7 MHz (T), and coordinates are N39 39.5 W085 42.0.
- Final Segment:** From Indianapolis VOR, a heading of 297° leads to the **INDIANAPOLIS INTL** airport, located at Eagle Creek ECR.

A north arrow indicates the orientation, pointing upwards. The text "NOT TO SCALE" is present near the north arrow.

**Notes**

The pilot participants were asked to use the simulator Mode Control Panel (MCP) for all ownship aircraft inputs – primarily airspeed, flaps, and speed brake. No heading changes were necessary. The primary task of the participants was to “safely, but expeditiously” close to 3nm behind the proximal lead aircraft while meeting all altitude and speed crossing restrictions. Participants were advised that should they close to less than 3nm behind the proximal lead aircraft, they should prioritize a return to the target spacing of 3nm.

Dependent measures comprised a broad array of flight data output sampled once a second during each trial. Included were ownship airspeed, vertical speed, altitude, flap and speed brake deployment, fuel burn, and relative distance to the proximal lead aircraft.

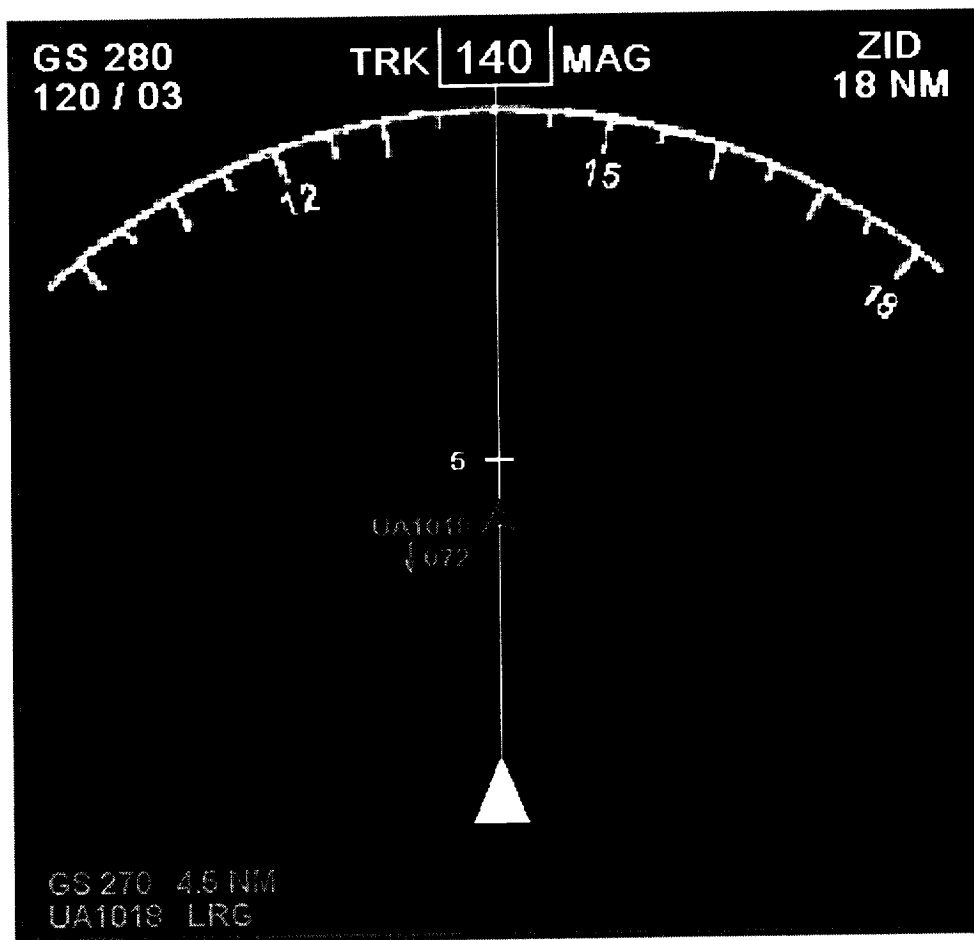
*miniACFS Simulator* – The miniature Advanced Concepts Flight Simulator (miniACFS) is a static, desktop version (see Figure 4) of the full size, full motion ACFS located at the NASA Ames Crew Vehicle Systems Research Facility. The miniACFS represents a generic twin-engine commercial jet transport with the aerodynamics and flying characteristics of a Boeing 757. The mode control panel (MCP) and flight management computer (FMC) replicate the type of equipment used in Boeing 757 class aircraft. The flight instrumentation (PFD/NAV/EICAS) replicates that used in the Boeing 747-400. All miniACFS inputs are made using touch pads.

**Figure 4.** MiniACFS environment.



*CDTI* – The Cockpit Display of Traffic Information (see Figure 5) was a Primary Flight Display-sized unit presented on the miniACFS center screen. Ownship and traffic were represented by distinct chevrons. The proximal lead aircraft, when present, was highlighted in green and its flight ID, ground speed, and distance from ownship were dynamically presented in the bottom left of the CDTI display.

**Figure 5.** Cockpit Display of Traffic Information.



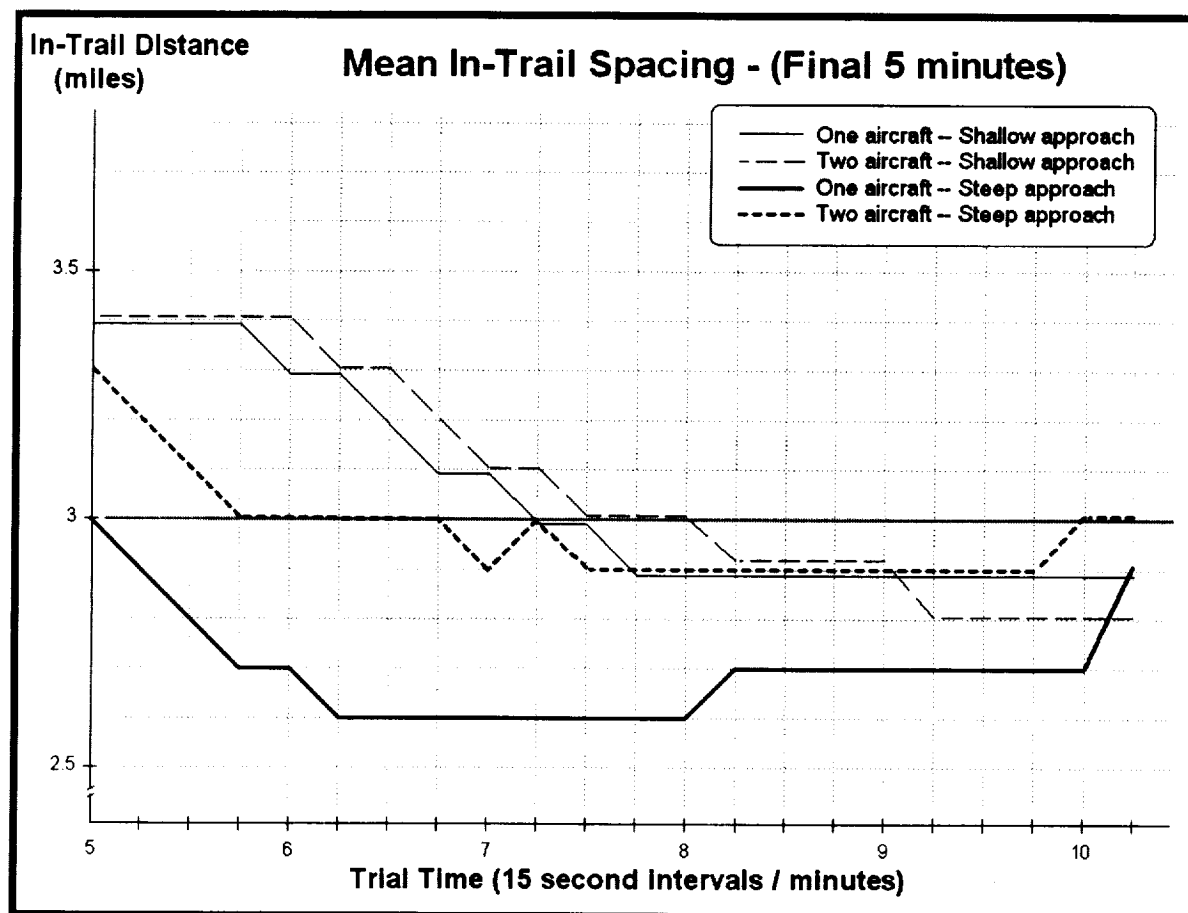
## Results

Within-subject ANOVAs were conducted on flight data measures related to both variables, lead aircraft presence (none, one, and two), and descent profile (shallow and steep).

With respect to the first study goal, participant performance with one and two downstream CDTI aircraft present across both descent profiles was examined. Only when a single downstream aircraft in a steep descent profile was presented, did participant performance deteriorate relative to the other conditions tested, see Figure 6.

Examining the “one (lead) aircraft” conditions only, in-trail spacing performance was significantly poorer in steep descents, as opposed to shallow descents,  $F(1,7)=6.052$   $p<.05$ . Comparing only the “two (lead) aircraft” conditions (for shallow vs. steep descents) did not reveal any performance difference based on descent profile.

Figure 6. Mean In-Trail Spacing for each condition with downstream aircraft present.



Examining the “steep approach” conditions, in-trail spacing at the target distance of 3nm trended toward being significantly poorer when only a single downstream aircraft was present,  $F(1,7)=3.693$   $p=0.096$ . Comparing

the “shallow approach” conditions (with one vs. two aircraft present) did not reveal any performance difference based on number of aircraft visible on the CDTI.

Average total time spent in violation of the 3nm spacing target also illustrates the poorer performance when only a single downstream aircraft was present in a steep descent approach (see Table 2). Average trial time spent inside 3nm of the proximal lead aircraft was 4m 42s in the steep approaches when only a single downstream aircraft was presented, versus an average of 2m 46s when two downstream aircraft were present on the CDTI.

**Table 2.** Mean time less than 3nm from proximal lead aircraft, in seconds.

	Shallow Descent Profile	Steep Descent Profile	Mean Time
One Downstream Aircraft	140	282	211
Two Downstream Aircraft	150	183	166

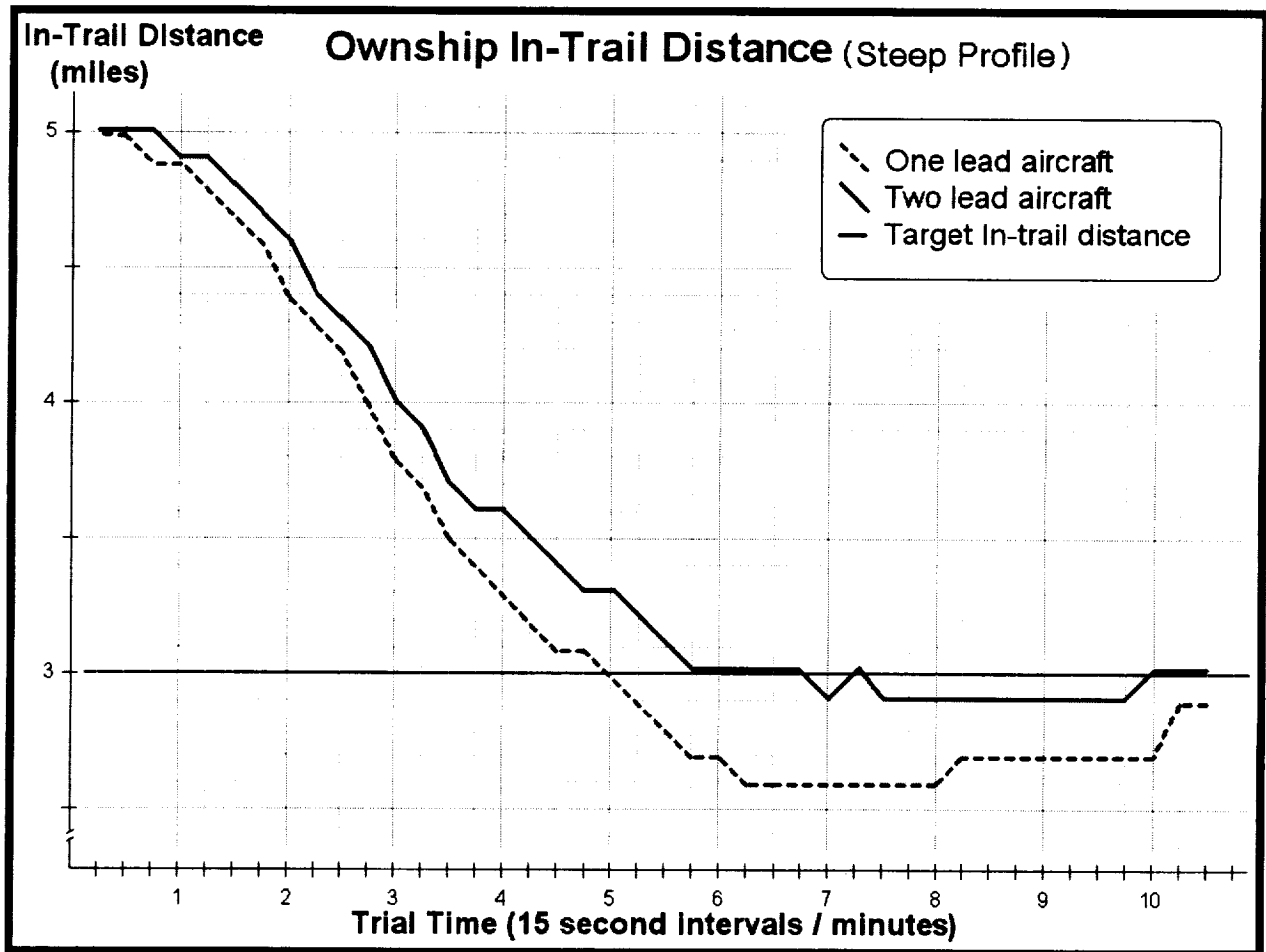
On every trial, participants met the required crossing restrictions for shallow and steep descents. A check of ownship fuel burn did not reveal any significant difference for number of aircraft present or descent profile.

## Discussion

Two performance-related observations from the study are of potential relevance to future CE11 research. *First*, with respect to the number of aircraft visible on the CDTI, the presence of multiple down-stream aircraft in-trail appeared to positively affect closure and spacing maintenance performance during 'steep' descent trials (see figure 7). In those instances when only a single downstream aircraft was present during a steep descent trial, participants routinely closed to less than 3nm behind the lead aircraft, approaching to within 2.6nm on average.

In those instances when a second downstream aircraft was present during steep descent trials, participants less frequently closed to within 3nm behind the immediate lead aircraft, and the resulting violation was limited to one-tenth of a mile on average.

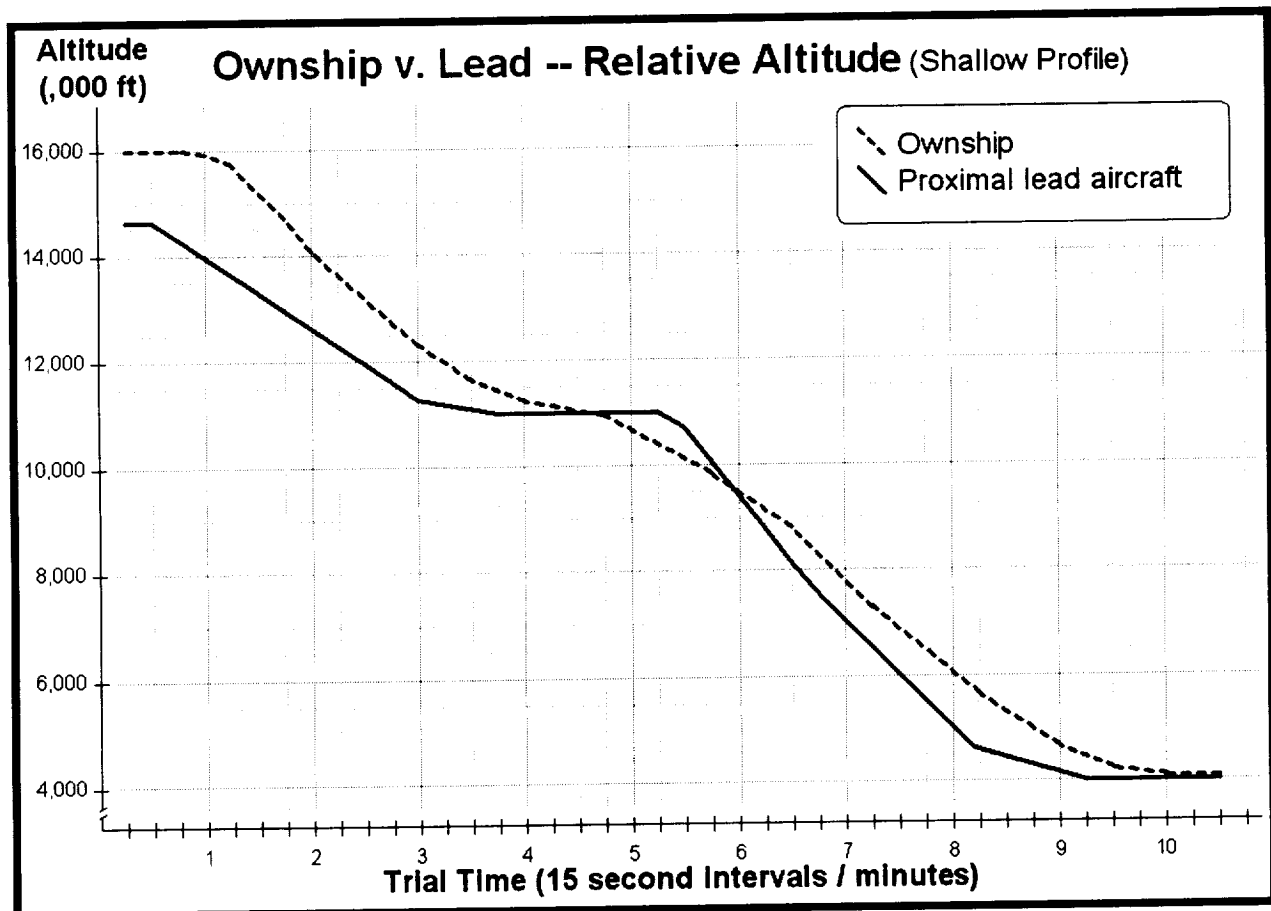
**Figure 7.** Ownship in-trail distance relative to proximal lead aircraft – steep profile.



It may be the case in the steep descent trials with only one downstream aircraft present, that the dynamic flight changes in that proximal lead aircraft, communicated to the participant via the CDTI, were so near-term that participant ownship responses needed to be relatively aggressive – be reactive – and that this perhaps translated into the poorer in-trail spacing seen. Conversely, with two downstream aircraft present during steep descent trials, it may have been the case that the most forward aircraft provided flight change information that permitted ownship participants to better anticipate the actions of the more proximal lead aircraft – to be proactive – resulting in the relatively better in-trail spacing seen.

A *second* observation was that in shallow descent trials, participants routinely descended *below* the lead aircraft's altitude (see figure 8 and Table 3, below), reinforcing that wake turbulence is a critical factor during closely spaced in-trail approaches, and illustrating that traditional STARs may not necessarily be well-suited to such approach procedures. (Many of the previous in-trail approach studies have used some form of "straight-in" profile, which does not always accurately reflect the infrastructure or operating constraints of the existing NAS.)

**Figure 8.** Ownship altitude relative to proximal lead aircraft – shallow profile.



**Table 3.** Trial time, mean and lowest altitude of ownship *below* proximal lead aircraft (shallow profile).

	One Lead Aircraft			Two Lead Aircraft		
Participant	Time (minutes)	Mean (feet)	Lowest (feet)	Time (minutes)	Mean (feet)	Lowest (feet)
1	3.25	361	684	0.75	424	602
2	0.00*	0	0	1.00	396	596
3	1.25	182	380	1.00	140	166
4	0.75	376	555	0.00*	0	0
5	2.00	634	1126	2.75	821	1370
6	0.75	193	305	1.25	195	293
7	1.00	245	407	1.25	347	534
8	1.25	539	806	2.00	455	714
Mean	1.28	316	533	1.25	347	534

Time = total trial time when ownship altitude was below that of the proximal lead aircraft.

Mean = average altitude by which ownship descended below the lead aircraft during a descent.

Lowest = the maximum number of feet ownship descended below the lead aircraft.

\* = Ownship altitude never fell below that of the proximal lead aircraft.

The conflict in relative altitudes may also highlight the significance of individual aircraft ‘handling’ characteristics. The proximal aircraft in each trial mirrored a Boeing 737-200 in terms of flight dynamics, while ownship was a considerably larger B-757. It is not clear, however, whether the relative altitude anomaly resulted from 1) ownship – a larger and less responsive B-757 – being physically unable to comply, 2) from a conscious decision on the part of pilot participants, having met the altitude crossing restriction, that the lead aircraft’s relative altitude was not a consideration, 3) that being a B-757 wake turbulence from a B-737 was not of consequence, or 4) that lead aircraft altitude simply went unnoticed.

*The results do, however, highlight the need for vertical profile information and wake turbulence hazards to be integrally and clearly communicated parts of any flight deck DST display supporting this type of procedure; automation of the approach and/or exact in-trial spacing process notwithstanding.*

In terms of participant feedback, several de-brief responses were of interest. When asked what degree of responsibility they would want Air Traffic Control to maintain during a “non-VFR spacing” approach such as



experienced during the study, all participants indicated they would want ATC to be actively overseeing the activity, but intervening “only if safe separation was likely to be compromised.”

Asked to respectively rate the overall difficulty of the task with one and two downstream aircraft present, none of the respondents rated either as being more difficult than the other (see Table 4, below). This participant reporting stands in contrast with the in-trail spacing performance noted above (see Figure 7), where the presence of a single downstream aircraft resulted in a prolonged 3nm separation violation relative to a proximal lead aircraft. Asked if having a second, distal aircraft present on the CDTI was helpful in completing the closure and spacing maintenance task, the “not helpful” mean response also stands in contrast with the better performance overall when two downstream aircraft were present on the CDTI.

**Table 4.** Selected participant de-brief responses.

Question	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	S <sub>4</sub>	S <sub>5</sub>	S <sub>6</sub>	S <sub>7</sub>	S <sub>8</sub>	Mean
Q1. With only one downstream aircraft present, how difficult was the task of closing and maintaining a 3nm separation?	3	5	4	4	5	4	4	5	4.3
Q2. With two downstream aircraft present, how difficult was the task of closing and maintaining a 3nm separation?	3	5	4	4	5	4	4	5	4.3
Q3. When present, how helpful was having a second, distal aircraft downstream in-trail?	1	3	1	1	2	2	1	2	1.6

(Q1 and Q2: 1 = very difficult, 7 = very easy. Q3: 1 = not very helpful, 7 = very helpful.)

In response to the question, *Have you ever used TCAS to (unofficially) maintain in-trail separation?* three respondents indicated no. The five which responded in the positive described their use as follows:

- *On final approach in IMC, ATC assigns speeds, but I will “fudge” on the speed to maintain in-trail separation. To avoid a tower directed M.A. (missed approach).*
- *On final approach use TCAS for spacing, wake vortices, etc.*
- *Approach in-trail.*
- *Final approach, overtaking small aircraft, to reduce speed to maintain spacing.*
- *Monitoring position behind another aircraft while landing, inside the O.M. (outer marker).*

## **Conclusions**

The preliminary study reported on here collected a set of baseline data on distance-based in-trail approach spacing, and highlighted some aspects of the procedure that may need to be considered in moving forward with CE11 research. Juxtaposed to isolating only the lead and trailing aircraft on a flight deck display during approach, having additional downstream traffic visible may be advantageous to the trailing aircraft in providing a long(er)-term ‘picture’ of events.

It may also be the case that the use of traditional STARs with a CDTI-type display for spacing on approach, may be complicated by wake turbulence considerations and the current ‘step down’ nature of many TRACON-managed approaches into major U.S. airports. Many in-trail approach studies in the past have made use of “straight-in” approach descents, unobstructed by either geographic or ATC airspace restrictions. Given that such ‘obstacles’ are routinely a part of the terminal environment, future research should consider this aspect in the design and testing of FD-based display equipment, in time-based in-trail spacing, in any modification of operational procedures, and in the algorithmic logic employed to manage aircraft spacing during approach.

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## **Appendix A**

### **Literature Review – Citations and Abstracts**

#### **ADS-B/CDTI capabilities for near-term deployment - Some early results**

Mundra, Anand; Cieplak, James C.; Domino, David A.; Olmos, Baltazar O.; Stassen, Hans P. (MITRE Corp., McLean, VA) In: AIAA/IEEE Digital Avionics Systems Conference (DASC), 16th, Irvine, CA, Oct. 26-30, 1997, Proceedings. Vol. 1 (A98-14005 02-01), Piscataway, NJ, Institute of Electrical and Electronics Engineers, Inc., 1997, p. 3.1-28 to 3.1-35. 1997

##### **Abstract**

This paper documents a proposed set of near-term applications of a cockpit display of traffic information (CDTI), which may be deployed in terminal and oceanic regions. It presents some results of simulations to determine the efficacy of specific CDTI information facilitating some of the early steps in this evolution. These formulations and results are being used by RTCA in developing minimum operational performance standards for a CDTI.

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#### **Advanced commercial cockpit concepts**

Miles, W. L.; Miller, J. I.; Variakojis, V. (Douglas Aircraft Co., Long Beach, CA) IN: Behavioral Objectives in Aviation Automated Systems Symposium; Proceedings of the Aerospace Congress and Exposition, Anaheim, CA, October 25-28, 1982 (A84-41051 19-54). Warrendale, PA, Society of Automotive Engineers, Inc., 1982, p. 103-123. 1982

##### **Abstract**

Recent developments in the cockpits of commercial transport aircraft are related to a digital auto flight guidance system, the introduction of the first production head-up display (HUD), the employment of electronic cathode-ray tubes (CRT) flight instruments, and engine/caution/warning displays. The present investigation is concerned with the reasons for the occurrence of these developments and with the final results which will be produced by the continuing changes in cockpit design. It is pointed out that two major developments combined in recent years to revolutionize flight deck technology. The first was the increase in large-scale integration (LSI) of electronic circuitry, while the second is related to the development of full color CRT's with adequate performance, size, reliability, and operability. Attention is given to the impact of new flight deck technology, flight deck design objectives and philosophy, a flight deck development approach, and the advanced commercial cockpit at an American aircraft manufacturer.

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#### **Advanced flight deck for next generation aircraft**

Faerber, R. A.; Etherington, T. J. (Rockwell Collins, Cedar Rapids, IA) In: DASC - AIAA/IEEE/SAE Digital Avionics Systems Conference, 17th, Bellevue, WA, Oct. 31-Nov. 7, 1998, Proceedings. Vol. 1 (A99-28776 07-01), Piscataway, NJ, Institute of Electrical and Electronics Engineers, Inc., 1998, p. E42-1 to E42-8. 1998.

##### **Abstract**

Alternative Flight Management System (FMS) human interface and Advanced Primary Flight Display (PFD) concepts are needed as the complexities of understanding and operating increased functionality on equipment continue to burden and confuse an already inundated pilot. Two independent human factors experiments were conducted in 1997. The first investigated the Advanced FMS Interface display format vs. a conventional Control Display Unit (CDU) type FMS. The second examined an advanced 3D PFD, an adaptation of the NASA 3D

pathways display, compared to a standard commercial PFD format. Results from both experiments revealed statistically significant findings at the 95th level of confidence favoring these advanced flight deck designs. The Advanced FMS Interface display format produced quicker reaction times and lower levels of mental workload than the conventional CDU. Likewise, the advanced 3D PFD format resulted in less tracking error in both lateral and vertical axis, lower levels of mental workload, and increased situational awareness. It is concluded that this type of advanced flight deck design has great potential for significantly reducing and/or eliminating human interface problems between users and the systems they interface with while at the same time reducing pilot mental workload and increasing situational awareness. This report details these findings and provides recommendations to cockpit designers of the next generation aircraft.

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### **Advanced image manipulation controllers for cockpit LCD displays**

Ramachandran, Gopal (Genesis Microchip Corp., Mountain View, CA) In: Cockpit displays V: Displays for defense applications; Proceedings of the Meeting, Orlando, FL, Apr. 15-17, 1998 (A99-12251 01-31), Bellingham, WA, Society of Photo-Optical Instrumentation Engineers (SPIE Proceedings. Vol. 3363), 1998, p. 172-180. 1998

#### **Abstract**

Key features of a family of LSI integrated circuits are explained. These DSP devices are capable of taking digital inputs of either NTSC/PAL/SECAM video in YCrCb 4:2:2 format, or computer graphics data from a PC in RGB 8:8:8 format, de-interlacing the data (if required), then re-sizing the resolution of the image independently in the horizontal and vertical axes to fit arbitrary display resolutions. The devices use patented digital filter techniques to perform zoom-only or both zoom as well as shrink. The devices also include registers that allow for cropping the active input image, and registers to completely control horizontal and vertical fuming parameters for LCD displays. Current members of this family work at clock rates of up to 84 MHz, at resolutions of 1024x768, and upcoming members of the family will raise both the target resolution and pixel rates. All these parts generate all timing signals required by the display. Typically, no external memory is required for zooming and shrinking. Cockpit display applications that could benefit from this chip include processing and display of video, FLIR, EFIS/EICAS displays, radar, digital terrain maps, ultrasonic/sonar, computer graphics/symbol generators, etc.

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### **Advanced symbology for general aviation approach to landing displays**

Bryant, W. H. National Aeronautics and Space Administration. Langley Research Center, Hampton, VA. In its Controls, Displays and Inform. Transfer for Gen. Aviation IFR Operations p 141-153 (SEE N84-12029 03-01) Oct. , 1983

#### **Abstract**

A set of flight tests designed to evaluate the relative utility of candidate displays with advanced symbology for general aviation terminal area instrument flight rules operations are discussed. The symbology was previously evaluated as part of the NASA Langley Research Center's Terminal Configured Vehicle Program for use in commercial airlines. The advanced symbology included vehicle track angle, flight path angle and a perspective representation of the runway. These symbols were selectively drawn on a cathode ray tube (CRT) display along with the roll attitude, pitch attitude, localizer deviation and glide slope deviation. In addition to the CRT display, the instrument panel contained standard turn and bank, altimeter, rate of climb, airspeed, heading, and engine instruments. The symbology was evaluated using tracking performance and pilot subjective ratings for an instrument landing system capture and tracking task.

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### **(An) aid to facilitate cockpit task management performance**

Kim, J., and Funk, K. (1995). In Proceedings of the 8th International Symposium on Aviation Psychology, Columbus, OH (pp 196A – 196E).

#### **Abstract**

A study was conducted to determine the technical feasibility of a Cockpit Task Management System (CTMS) via the development of a prototype CTMS and to evaluate CTMS effectiveness in order to improve CTM performance. The results show that if an aid can accurately determine what tasks the pilot is attempting to complete and how well the tasks are being performed, CTM performance can be facilitated by displaying relevant task management information; in particular, calling the pilot's attention to tasks which are not being performed in a satisfactory or timely manner.

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### **Aircraft automatic approach and landing using GPS**

Parkinson, Bradford W.; O'Connor, Michael L. (Stanford Univ., CA); Fitzgibbon, Kevin T In: Global Positioning System: Theory and applications. Vol. 2 (A96-20837 04-17), Washington, DC, American Institute of Aeronautics and Astronautics, Inc. (Progress in Astronautics and Aeronautics. Vol. 164), 1996, p. 397-425.1996

#### **Abstract**

Autopilot systems based on GPS are not only less expensive than those based on instrument landing and microwave landing capabilities; they also obviate costly air and ground equipment, and are not confined to approaches within a narrow radar beam. It is noted that GPS sensor measurements are inherently better suited for autopilot use; GPS measures position in 3D, and offers highly accurate velocity measurements.

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### **Aircraft landing - A total systems approach**

Papadopoulos, C.; Self, A. W. (Kingston Univ., Kingston upon Thames, United Kingdom); Kapadoukas, G. G. (CAE Invertron, United Kingdom) ICAS, Congress, 21st, Melbourne, Australia, Sept. 13-18, 1998, 8 p.. Sep. , 1998 Report Number: ICAS Paper 98-1,11,2

#### **Abstract**

This paper describes the developments made so far in the design and development of an auto-land system for optimizing aircraft landing performance. The system takes into account the all-axes aerodynamic and mechanical behavior of the aircraft at the point of touchdown and landing. The aim is to develop a system that automatically applies the control action to the appropriate aerodynamic and braking systems causing the aircraft to come to rest in an optimal and controlled manner, taking into account weather and runway conditions. The new controller will use main wheel braking from the moment the main gear contacts the runway surface and the wheel velocities match that of the ground. The controller will command the ailerons and main wheel brakes to aid in braking and the ailerons, rudder, nose wheel steering, and differential braking to maintain directional stability. A nonlinear simulation of a Boeing 747 has been used as a test bed. The paper described the theory, rationale, and test results received from the nonlinear test bed.

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### **Analysis of delay reducing and fuel saving sequencing and spacing algorithms for arrival traffic**

Neuman, Frank; Erzberger, Heinz National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA. Oct. , 1991 , 44P. Announcements: Supersedes NASA-TM-102795 Report Number: NASA-TM-103880; A-91203; NAS 1.15:103880

#### **Abstract**

The air traffic control subsystem that performs sequencing and spacing is discussed. The function of the sequencing and spacing algorithms is to automatically plan the most efficient landing order and to assign optimally spaced landing times to all arrivals. Several algorithms are described and their statistical performance is examined. Sequencing brings order to an arrival sequence for aircraft. First-come-first-served sequencing (FCFS) establishes a fair order, based on estimated times of arrival, and determines proper separations. Because of the randomness of the arriving traffic, gaps will remain in the sequence of aircraft. Delays are reduced by time-advancing the leading aircraft of each group while still preserving the FCFS order. Tightly spaced groups of aircraft remain with a mix of heavy and large aircraft. Spacing requirements differ for different types of aircraft trailing each other. Traffic is reordered slightly to take advantage of this spacing criterion, thus shortening the groups and reducing average delays. For heavy traffic, delays for different traffic samples vary widely, even when the same set of statistical parameters is used to produce each sample. This report supersedes NASA TM-102795 on the same subject. It includes a new method of time-advance as well as an efficient method of sequencing and spacing for two dependent runways.

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### **Analysis of estimation algorithms for CDTI and CAS applications (Final Report)**

Goka, T. Analytical Mechanics Associates, Inc., Mountain View, CA. Apr. , 1985 , 216P. Report Number: NASA-CR-172444; NAS 1.26:172444 Contract Number: NAS 1-16135; RTOP 505-35 13-03

#### **Abstract**

Estimation algorithms for Cockpit Display of Traffic Information (CDTI) and Collision Avoidance System (CAS) applications were analyzed and/or developed. The algorithms are based on actual or projected operational and performance characteristics of an Enhanced TCAS II traffic sensor developed by Bendix and the Federal Aviation Administration. Three algorithm areas are examined and discussed. These are horizontal x and y, range and altitude estimation algorithms. Raw estimation errors are quantified using Monte Carlo simulations developed for each application; the raw errors are then used to infer impacts on the CDTI and CAS applications. Applications of smoothing algorithms to CDTI problems are also discussed briefly. Technical conclusions are summarized based on the analysis of simulation results.

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### **Analysis of future navigation requirements for higher capacity in terminal maneuvering areas**

Mohleji, S. C.; Zeltser, M. J. (Mitre Corp., McLean, VA) IN: PLANS '82 - Position Location and Navigation Symposium, Atlantic City, NJ, December 6-9, 1982, Record (A84-12426 02-04). New York, Institute of Electrical and Electronics Engineers, 1982, p. 189-197. Sponsorship: U.S. Department of Transportation. 1982 Contract Number: DOT-A01-82-C-10003

#### **Abstract**

In this paper, the performance requirements of accuracy, coverage and channel capacity for a rho/theta navigation system are analyzed for congested terminal maneuvering areas (TMA). The TMA environment assumed automated air traffic control (ATC) and homogeneous traffic where all aircraft are equipped with flight management systems. The accuracy requirements are determined from the interrelationship between ATC procedures and navigation

system performance. This is accomplished by estimating the impact of uncertainties in navigation, ground speed estimation including winds, surveillance and delay in communications on the landing time dispersions. The coverage requirement is derived by analyzing the impact of navigation system transition between the en route and TMA at 10 high density airports. The channel capacity is determined by estimating the number of aircraft that can request navigation service simultaneously. In addition, a methodology is presented to compare navigation system implementation based on economic considerations, that can be used by any country to assess their own needs.

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#### **Analysis of in-trail following dynamics of CDTI-equipped aircraft**

Sorensen, J. A., and Goka, T. (1982). In Proceedings of 9th AIAA Atmospheric Flight Mechanics Conference, San Diego, CA. AIAA paper 82-1330.

##### **Abstract**

In connection with the necessity to provide greater terminal area capacity, attention is given to approaches in which the required increase in capacity will be obtained by making use of more automation and by involving the pilot to a larger degree in the air traffic control (ATC) process. It was recommended that NASA should make extensive use of its research aircraft and cockpit simulators to assist FAA in examining the capabilities and limitations of cockpit displays of traffic information (CDTI). A program was organized which utilizes FAA ATC (ground-based) simulators and NASA aircraft and associated cockpit simulators in a research project which explores applications of the CDTI system. The present investigation is concerned with several questions related to the CDTI-based terminal area traffic tactical control concepts. Attention is given to longitudinal separation criteria, a longitudinal following model, longitudinal capture, combined longitudinal/vertical control, and lateral control.

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#### **(An) analysis of landing rates and separations at the Dallas / Fort Worth International airport**

Ballin, M. G. and Erzberger, H. (1996). "An analysis of landing rates and separations at the Dallas / Fort Worth International airport." NASA Technical Memorandum 110397, National Aeronautics and Space Administration.

##### **Abstract**

Advanced air traffic management systems such as the Center/TRACON Automation System (CTAS) should yield a wide range of benefits, including reduced aircraft delays and controller workload. To determine the traffic-flow benefits achievable from future terminal airspace automation, live radar information was used to perform an analysis of current aircraft landing rates and separations at the Dallas/Fort Worth International Airport. Separation statistics that result when controllers balance complex control procedural constraints in order to maintain high landing rates are presented. In addition, the analysis estimates the potential for airport capacity improvements by determining the unused landing opportunities that occur during rush traffic periods. Results suggest a large potential for improving the accuracy and consistency of spacing between arrivals on final approach, and they support earlier simulation findings that improved air traffic management would increase capacity and reduce delays.

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#### **APALS - Autonomous Precision Approach and Landing System**

Dieffenbach, Otto (Lockheed Martin Corp., Rancho Bernardo, CA) In: Institute of Navigation, Annual Meeting, 51st, Colorado Springs, CO, June 5-7, 1995, Proceedings (A96-14001 02-32), Alexandria, VA, Institute of Navigation, 1995, p. 247-251. 1995



## Abstract

The APALS system is a precision approach and landing system designed to enable low visibility landings at many more airports than is now possible. It is an autonomous navigation system which uses standard avionics equipment to determine the aircraft position and altitude with respect to unique features over which the aircraft flies. The primary measurement is made with the aircraft's weather radar and provides the range and range rate information necessary to update the precision navigation system. The system makes use of stored terrain map data as references for map matching with SAR maps.

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## Application of an autonomous landing guidance system for civil and military aircraft

Franklin, Michael R. (Lear Astronics Corp., Santa Monica, CA) In: Synthetic vision for vehicle guidance and control; Proceedings of the Conference, Orlando, FL, Apr. 17, 18, 1995 (A95-38227 10-06), Bellingham, WA, Society of Photo-Optical Instrumentation Engineers (SPIE Proceedings. Vol. 2463), 1995, p. 146-153. 1995

## Abstract

This research has focused on providing aircraft users with both enhanced performance and a cost-effective landing solution with less dependence on ground systems, and has interested both the military and civil aircraft operator communities. The Autonomous Landing Guidance (ALG) system provides the capability to land in low visibility by displaying to the pilot an image of the real world without the need for an onboard Category II or III (CAT II/III) auto-land system and without the associated ground facilities normally required. Besides the inherent advantage of saving the cost of expensive installations at airports, ALG also has the effect of inevitably solving the airport capacity problem, weather-related delays and diversions, and airport closures. Low visibility conditions typically cause the complete shutdown of smaller regional airports and reduces the availability of runways at major hubs, which creates a capacity problem to airlines.

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## Application of CRT displays to the cockpit of tomorrow

Dandekar, A. J. (Rockwell International Corp., Collins Air Transport Div., Cedar Rapids, Iowa) Society of Automotive Engineers, Aerospace Congress and Exposition, Los Angeles, Calif., Oct. 13-16, 1980, 8 p. Oct. , 1980  
Report Number: SAE PAPER 801168

## Abstract

The 757/767 and A310 airliners' Electronic Flight Instrument System (EFIS) generally, and the 757 Engine Indication and Crew Alerting System (EICAS), A310 Electronic Warning and System Displays (EWSD), and 767 Caution Annunciator Indicator (CAI) systems in particular, are examined to show an extensive and refined use of CRTs and associated display graphics. The shadow mask CRTs employed offer the full color spectrum for displays, and use integral contrast enhancement filters in conjunction with high-resolution shadow mask tubes to make the displays exceptionally readable under all lighting conditions. The architecture of the display systems presented reflects the consensus of the air transportation industry, based on operational requirements, technological considerations, regulatory and installation constraints, and reliability, maintainability, and support considerations.

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## Applications of the airborne traffic situation display in air traffic control

Connelly, M. E. (MIT, Cambridge, Mass.) In: NEREM 74; Northeast Electronics Research and Engineering Meeting, Boston, Mass., October 28-31, 1974, Record. Part 1. (A75-39191 19-32) Newton, Mass., Institute of Electrical and Electronics Engineers, Inc., 1974, p. 19-21. 1974

## Abstract

The paper reviews past and present simulation experiments with an airborne traffic situation display (ATSD) and discusses the potential role of this device in future air traffic control systems. In a three-year period, the operational value of the ATSD was evaluated in tests in which Boston's Logan International Airport was used to provide a realistic approach environment. It was found that the cockpit display enabled pilots to merge and to space themselves in trail more closely and much more precisely than is possible with present-day radar vectoring techniques and that the resultant pilot workload did not exceed acceptable limits. The ATSD is currently being evaluated in monitoring of runway occupancy during an approach, airport surface navigation and conflict avoidance, discrete address metering and spacing, and display of ground-derived and air-derived severe weather information.

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## Approach procedures (human factor considerations for safe landing of aircraft)

Hoagland, M. (United Air Lines, Inc., Denver, Colo.) In: Safety and efficiency: The next 50 years; Proceedings of the Symposium on Human Factors in Civil Aviation, The Hague, Netherlands, September 3-7, 1979. (A80-53554 24-03) Amstelveen, Netherlands, Vereniging van Nederlandse Verkeersvliegers, 1980, p. 83-90; Discussion, p. 91-93. 1980

## Abstract

Results of an analysis of the standard operating procedures of an airline with regard to the approach and landing phase of aircraft operation are discussed. It is noted that a procedure should reflect the needs of those who use it, particularly be operationally excellent, pragmatic and inspire self-discipline, and the necessary cockpit environment for the safe approach and landing of an aircraft is considered. Based on these considerations and the opinions and suggestions of airline pilots, a set of standard operating procedures is formulated which greatly improve crew utilization, expand the flexibility afforded the captain and would apply equally well to instrument and VFR approaches.

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## Approach Station Keeping (ASK) Experiment Plan and Final Report

U.S. DoT, FAA, DOT/FAA/CT-TN95/58, December 1995.

## Abstract

The Approach Station Keeping (ASK) study was conducted at the request of the Federal Aviation Administration's (FAA's) Flight Standards Organization (AFS-400) to investigate an issue raised by RTCA Special Committee - 186 concerning implementation of the proposed Automatic Dependent Surveillance-Broadcast (ADS-B) system. The primary study objective was to investigate whether both Indicated Air Speed (IAS) and Ground Speed (GS) of a leading aircraft were required by the flight crew of a trailing aircraft to maintain separation. The secondary study objective was to investigate whether provision of IAS information of a leading aircraft would enable the flight crew of a trailing aircraft to detect the presence of wind shear. The test bed consisted of the FAA's Re-configurable Cockpit Simulator (RCS) and General Aviation Trainer (GAT) located at the FAA Technical Center in Atlantic City, NJ. The RCS was configured as a Boeing 747-400 aircraft and flown as the trailing aircraft. The GAT was flown as the leading aircraft at approach and landing speeds corresponding to a Beechcraft Super King Air (BE-20). The dynamic position of the leading aircraft, a data block containing call sign, type aircraft, and GS or GS and IAS of the leading aircraft, and a three mile range ring were incorporated in the Navigation Display of the trailing aircraft. Five flight crews conducted 24 approaches each. The wind condition, starting position, configuration and speed, airspeed option, and control mode (autopilot or manual) were varied for each approach. Analysis of subjective and objective data indicated that IAS did not appear to provide an advantage for maintaining instantaneous separation. However, IAS seemed to help pilots as a planning tool for predicting winds, and thereby

anticipating the potential loss of separation. The study concluded that the presentation of GS is sufficient to maintain separation, however, if the objective is to identify wind shear, IAS is required.

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#### **Arrival and departure traffic management within the terminal area**

Schubert, Manfred (DLR, Braunschweig, Germany) AIAA, Guidance, Navigation and Control Conference, San Diego, CA, July 29-31, 1996, 11 p., Jul. , 1996 Report Number: AIAA Paper 96-3720

##### **Abstract**

Within the European ATM scenario foreseen in the next 10 to 15 years, a significant part of the commercial aircraft will be equipped with 4D flight management systems and data link. To take advantage of the more precise trajectory prediction capability a number of tools must be organized, e.g. arrival and departure traffic within the terminal area. This paper describes the structure of such an integrated ATC tool environment on the ground. Within the envisaged scenario the new ATM functions have to deal with control procedures that are still based on the main characteristics of the present-day system. This means that the human functions planning and tactical control within each ATC sector will still exist and the sector concept will still remain, but planning, negotiation, and communication will be extended over the individual sector size. The goal is to define and demonstrate a multi-sector planning concept within the extended terminal area covering all flight phases of approaching and departing aircraft and to evaluate the enhancements with respect to performance, controller workload, and controller acceptance.

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#### **ATC delays - The number one problem in the next decade**

Pitas, A. F. (Air Transport Association, Washington, D.C.) In: Air Traffic Control Association, Annual Fall Conference, 23rd, Fort Worth, Tex., October 2-5, 1978, Proceedings. (A79-23580 08-04) Washington, D.C., Air Traffic Control Association, Inc., 1978, p. 92-98. 1978

##### **Abstract**

Ways of improving ATC system capacity and reducing delays are discussed. Attention is given to such possible solutions as new airports, new runways, reducing runway occupancy time, improved airport surface traffic control and guidance, decrease of longitudinal spacing between aircraft, improved ILS monitoring, improved manpower productivity, and improved flow management.

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#### **Automation overload? Human tracking and detection errors during aircraft flight**

Ramsden, J. M. (1994). Aerospace (UK), vol. 21, 4 (p 14-15).

##### **Abstract**

Several examples are presented to demonstrate that automation is not error-free and may introduce different kinds of errors affecting flight safety. The problem of the human-machine interface is addressed, and the importance of considering human factors in designing air traffic control systems is emphasized.

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## **Aviation displays**

Stokes, Alan F. (Illinois, University, Savoy); Wickens, Christopher D. (Illinois, University, Champaign) IN: Human factors in aviation (A89-34431 14-54). San Diego, CA, Academic Press, Inc., 1988, p. 387-431. Research supported by General Motors Corp. 1988

### **Abstract**

The design principles and characteristics of state-of-the-art cockpit displays are reviewed from the perspective of human-factors engineering. Topics addressed include flight-path displays (quickening and predictive displays), navigational displays, display organization and configuration, the visual overload problem, head-up displays, peripheral displays, speech and non-speech auditory displays, color displays, advanced cockpits, and display automation (decluttering and reconfiguration). Drawings, diagrams, and photographs of typical displays are provided. (179 references).

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## **Avionics systems of the 21st century**

Aerospace Engineering (ISSN 0736-2536), vol. 12, March 1992, p. 19-23. Mar. , 1992

### **Abstract**

Coupled with advancements in software partitioning, fault-tolerant electronics have reached a level of development in avionics-related applications which promise unprecedented availability and integration, as well as reduced installed system weight. In addition, the implementation of 'modularity' concepts to avionics design has allowed application-specific components to be furnished by tailoring various predefined modular elements to perform the required functions. Comparably far-ranging accomplishments are at hand for data transmission, as in the case of the fiber-optic transmission paths-based ARINC 629 two-way data-transmission buses: which bring immunity to intense EMI while yielding weight reductions. Cockpit display and flight-management computer technology benefits are evaluated, relative to conventional systems.

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## **Basic analysis of terminal operation benefits resulting from reduced vortex separation minima (for aircraft operation in terminal area)**

Credeur, L. National Aeronautics and Space Administration. Langley Research Center, Hampton, Va. Oct. , 1977 , 25P. Report Number: NASA-TM-78624

### **Abstract**

The impact of reducing the wake vortex minimum separation required behind heavy jets on terminal area operation rate was analyzed. The effect on arrival saturation and steady state average delay was determined for various percentages mix of heavy and large jet traffic samples operating under various precision of inter-arrival spacing. Benefits increase with percentage of heavy aircraft and with precision of control. These results demonstrate the payoff possible from research to reduce the severity of the trailing vortex by aerodynamic means.

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## **Boeing's design approach for crew-centered flight decks.**

Higgins, J. K. (1996). In Proceedings of the Conference, The Future Flight Deck – Safe and Friendly, London, UK Record (A96-28635 07-54).

## Abstract

Introduction of new functions to the flight deck are driven by many criteria. Safety, reliability, efficiency, commonality, and customer value are among the most familiar. When considering new or revised flight deck designs, the designer is faced with a multitude of options and requirements. Today's technology makes it possible to completely revise the way pilots operate airplanes. However, the pilots who will operate the airplane will do so based on their past flying experience. All airlines have similar operational requirements, but each airline has unique flight operations requirements. All airplanes must be compatible with the air traffic control environment. Yet, worldwide air traffic systems and procedures are not common. All pilots have similar skills, but cultural differences influence their interactions. Taken together, these factors sometimes create conflicting design requirements. Because safety is the prime consideration for any design, a set of guidelines and principles must be available to help the designer blend the final design into a cohesive whole. The central role that the flight crew plays in operational safety demands that these guidelines and principles be centered on the capability and limitations of the crew. A human-centered design is required. A human-centered design will result when the designer understands (1) the roles and responsibilities of the commercial jet pilot and (2) the capabilities of the human in that role, and (3) uses a set of design guidelines that recognize and complement the roles, responsibilities, and human capabilities. This paper reviews the Boeing Crew Centered Design Philosophy by outlining these three factors.

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### **(A) cockpit-display concept for executing a multiple glide-slope approach for wake-vortex avoidance**

Abbott, T. S. National Aeronautics and Space Administration. Langley Research Center, Hampton, VA. Feb. , 1984, 44P. Report Number: NASA-TP-2386; L-15852; NAS 1.60:2386 Contract Number: RTOP 505-35-13

## Abstract

A piloted simulation study was undertaken to determine the feasibility of utilizing a forward-looking display to provide information that would enable aircraft to reduce their in-trail separation interval, and hence increase airport capacity, through the application of multiple glide-path approach techniques. The primary objective of this study was to determine whether information could be satisfactorily provided on a head-up display (HUD) format to permit the pilot to conduct a multiple glide-slope approach while maintaining a pre-specified in-trail separation interval. The tests were conducted in a motion-base cockpit simulator configured as a current-generation transport aircraft and included dynamic effects of the vortices generated by the lead aircraft. The information provided on the HUD included typical aircraft guidance information and the current and past positions of the lead aircraft. Additionally, the displayed information provided self-separation cues that allowed the pilot to maintain separation on the lead aircraft. Performance data and pilot subjective ratings and comments were obtained during the tests. The results of this study indicate that multiple glide-slope approaches, procedurally designed for vortex avoidance, are possible while maintaining pilot work load and performance within operationally acceptable limits. In general, it would seem that multiple glide-slope approaches are possible even under reduced in-trail separation conditions if the pilot is provided with adequate situational information.

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### **Comparison of pilot variations following terminal area trajectories**

Slattery, Rhonda A.; Lee, Katharine K. (NASA, Ames Research Center, Moffett Field, CA); Sanford, Beverly D. (Sterling Software, Inc., Redwood City, CA) In: AIAA Guidance, Navigation, and Control Conference, New Orleans, LA, Aug. 11-13, 1997, Collection of Technical Papers. Pt. 2 (A97-37001 10-63), Reston, VA, American Institute of Aeronautics and Astronautics, 1997, p. 1193-1200. 1997 Report Number: AIAA Paper 97-3690

## Abstract

The automation being investigated to help air traffic controllers and pilots in all phases of flight requires accurate estimates of trajectories to predict and resolve conflicts between aircraft. A problem with creating trajectories in the terminal area is pilot variability when performing maneuvers. A full-mission flight simulation was performed, using a Boeing 747-400 six-degree-of-freedom simulator. One goal of the simulation was to examine the variability of maneuvers for aircraft equipped with three levels of on-board automation. Four variables were examined: time of flight, altitude, speed, and start of turns. Time of flight was examined to compare to previous experiments and was found to have the expected accuracy of  $\pm 15$  sec. Altitude maneuvers show significant variability, which needs to be resolved for accurate trajectory prediction. Speed maneuvers also had a wide variability, but take place over short periods in the trajectory. Consequently, their impact on trajectory prediction is minimal. The starts of turns varied by about 1 n. mi. Turn effects can be removed by using a flight management system to fly the route.

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## Comparison of speech and pictorial displays in a cockpit environment

Robinson, Christopher P. (USAF, Aeronautical Systems Div., Wright-Patterson AFB, OH); Eberts, Ray E. (Purdue University, West Lafayette, IN) Human Factors (ISSN 0018-7208), vol. 29, Feb. 1987, p. 31-44. Feb. , 1987

## Abstract

A current trend in cockpit design is to incorporate synthesized speech to present secondary information. Multiple-resource theories of information processing support this, but theories of stimulus/central-processing/response compatibility suggest that spatial information presented visually may have some advantages over speech if the response is manual. Two experiments compare response performance over single and dual tasks when information was presented pictorially and by speech. Pictorial subjects responded more quickly than did speech subjects. The addition of the visual tracking task in the dual-task condition had a differential effect on performance, depending on the modality of the primary task and the rate at which information was presented. The dual task impeded performance more in the fast and medium presentation rates for the speech condition but had little differential effect across rates for the pictorial condition. Analysis of the error data indicated that subjects in the pictorial condition were better able to maintain the context of the emergency than those in the speech condition. Results are discussed in terms of current theories of information processing. (24 Refs.)

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## Concept Definition for Distributed Air/Ground Traffic Management (DAG-TM) v1.0\*

Advanced Air Transportation Technologies Project, September 1999.

DAG-TM is a proposed concept for gate-to-gate NAS operations beyond the year 2015. The goal of DAG-TM is to enhance user flexibility/efficiency and increase system capacity, without adversely affecting system safety or restricting user accessibility to the NAS. The following is a list of the DAG-TM concept elements:

Gate-to-Gate:	Information Access/Exchange for Enhanced Decision Support
Pre-Flight Planning:	NAS-Constraint Considerations for Schedule/Flight Optimization
Surface Departure:	Intelligent Routing for Efficient Pushback Times and Taxi
Terminal Departure:	Free Maneuvering for User-Preferred Departures
Terminal Departure:	Trajectory Negotiation for User-Preferred Departures
En route:	(Departure, Cruise, Arrival)Free Maneuvering for: (a) User-preferred Separation Assurance, and (b) User-preferred Local TFM Conformance

En route:	(Departure, Cruise, Arrival)Trajectory Negotiation for: (a) User-preferred Separation Assurance, and (b) User-preferred Local TFM Conformance
En route:	(Departure, Cruise, Arrival)Collaboration for Mitigating Local TFM Constraints due to Weather, SUA and Complexity
En route / Terminal:	Collaboration for User-Preferred Arrival Metering
Terminal Arrival:	Free Maneuvering for Weather Avoidance
Terminal Arrival:	Trajectory Negotiation for Weather Avoidance
Terminal Arrival:	Self Spacing for Merging and In-Trail Separation
Terminal Arrival:	Trajectory Exchange for Merging and In-Trail Separation
Terminal Approach:	Airborne CD&R for Closely Spaced Approaches
Surface Arrival:	Intelligent Routing for Efficient Active-Runway Crossings and Taxi

#### **(A) concept for 4D-guidance of transport aircraft in the TMA (Terminal Maneuvering Area)**

Adam, V.; Lechner, W. (Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt, Brunswick, West Germany) In: International Council of the Aeronautical Sciences, Congress, 13th and AIAA Aircraft Systems and Technology Conference, Seattle, WA, August 22-27, 1982, Proceedings. Volume 1. (A82-40876 20-01) New York, American Institute of Aeronautics and Astronautics, 1982, p. 642-653. 1982

##### **Abstract**

The four dimensional (4D) guidance of aircraft in the TMA allows for precise control of the minimum separation and thus efficient use of the available approach capacity of the airport. A concept for the 4D-guidance of transport aircraft has been developed and a corresponding control mode has been integrated in an automatic flight control system for transport aircraft. The 4D mode is based on the usual radar vector guidance technique of air traffic control and, therefore, is characterized by a succession of flight sections with constant values for indicated airspeed, heading and descent rate. The time of arrival is controlled by altering the path via a delay fan. The algorithm for the calculation of the commanded 4D flight path takes into account suitable wind models updated by actual wind data. In the paper the 4D mode is described and first flight test results are discussed.

#### **Concepts for determination of longitudinal separation standards on final approach**

Haines, A. L. Mitre Corp., McLean, Va. METREK Div. Oct. , 1975 , 44P. Report Number: PB-274590/9; MTR-7047 Contract Number: DOT-FA70WA-2448

##### **Abstract**

Definitions are developed with a view toward identifying the relationships between separation standards and the variables describing the final approach environment. This provides a basis for systematic evaluation of changes in separation standards due to changes in the environment, particularly through Engineering and Development products. Analytical relationships are developed primarily for IFR conditions, represented by strict adherence to all applicable ATC rules and procedures. For modeling purposes, relationships are also developed for 'standards' for VFR conditions, represented by visual approaches from an IFR flight plan.

## **Decay of Wake Vortices of Large Aircraft**

Sarpkaya, Turgut (Naval Postgraduate School, Mechanical Engineering, Monterey, CA United States) NASA no. 19980073278. Proceedings of the NASA First Wake Vortex Dynamic Spacing Workshop. Nov. , 1997 Report Number: NASA no. 19980073278

### **Abstract**

A finite wing has three vortices: bound vortex, starting vortex, and the trailing vortex. It is primarily the trailing vortex/wake that can be very hazardous to following aircraft during cruise and especially during take-off and landing. This, in turn, gives rise to complex air-traffic-control and aircraft-handling problems. The safe longitudinal separation distance between consecutive aircraft is in part determined by the time interval the vortices require to decay and dissipate, or to breakup due to the onset of catastrophic instabilities (vortex linking or burst), or to be convected out of the flight path of the following aircraft by the combined action of their self induced velocity and wind. These processes are strongly influenced by the meteorological conditions such as ambient turbulence, wind shear, stratification, humidity and precipitation which can considerably effect the lifetime of the trailing vortices. The elimination or the reduction of the intensity of trailing vortices has the added advantages of reducing drag and increasing the aerodynamic efficiency of the wing. For an aircraft in landing configuration, extended flaps will result in variations in the span wise circulation distribution, which will result in a multi-vortex wake topology. The proximity of the ground, cross winds, ground heating, etc. have profound effects on the development of this already complex problem. Suffice it to note that, vortex decay in the atmosphere in cruising conditions is significantly different from that in landing/takeoff conditions. Near the ground, the vortices strongly interact with the ground boundary layer, may acquire non-circular cross-sections, cause flow separation on the ground, give rise to oppositely-signed vorticity (with additional ground-vortex images) and rebounding (by forming a vortex dipole between the heterostrophic and homostrophic vortices). Clearly, the determination of a safe aircraft separation is a very difficult problem and requires careful measurements in the field, meteorological data, and the reliable evaluation and interpretation of the results. The uniqueness of the problem comes not so much from the strong interaction between a man-made structure and the environment (normally, a bluff body problem), but rather from the interaction of the byproducts of this interaction with other bodies in a partially altered environment. It is also unique among the many complex and industrially challenging aerodynamics problems in the sense that the answer lies within a surprisingly small range of numbers (three to ten miles).

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## **Delay induced oscillations (pilot induced oscillation in approach and landing)**

Ionita, Achim (National Inst. for Aerospace Research, Bucharest, Romania); Halanay, Aristide (Bucharest, Univ., Romania) In: AIAA Atmospheric Flight Mechanics Conference, New Orleans, LA, Aug. 11-13, 1997, Collection of Technical Papers (A97-37244 10-08), Reston, VA, American Institute of Aeronautics and Astronautics, 1997, p. 201-205. 1997 Report Number: AIAA Paper 97-3502

### **Abstract**

In the landing transition between the approach task and flare to touch-down, pilot-induced oscillations (PIOs) can appear which currently are associated with control time-delay. The cumulative effect of the pilot-effective lag and the control time-delay in the resulting low-order models was used to evaluate the longitudinal flying qualities of aircraft and tendencies to PIOs. A prediction procedure in the preliminary design was originally developed using specified methods involving the qualitative theory of differential equations with delayed argument. A mathematical model of motion shows that oscillations appear when the quasi-polynomial enclosed system has solutions on the imaginary axis. The effect of pilot gain and control time delays in approach and flare tasks with pitch-rate flight control systems are discussed. Our applications of this technique give good predictions in agreement with the results of others authors.



**Design requirements and development of an airborne descent path definition algorithm for time navigation (Final Report)**

Izumi, K. H.; Thompson, J. L.; Groce, J. L.; Schwab, R. W. Boeing Commercial Airplane Co., Seattle, WA. May, 1986, 67P. Report Number: NASA-CR-178037; NAS 1.26:178037 Contract Number: NAS 1-16300; RTOP 505-45-33-11

**Abstract**

The design requirements for a 4D path definition algorithm are described. These requirements were developed for the NASA ATOPS as an extension of the Local Flow Management/Profile Descent algorithm. They specify the processing flow, functional and data architectures, and system input requirements, and recommended the addition of a broad path revision (re-initialization) function capability. The document also summarizes algorithm design enhancements and the implementation status of the algorithm on an in-house PDP-11/70 computer. Finally, the requirements for the pilot-computer interfaces, the lateral path processor, and guidance and steering function are described.

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**Development and test results of a precision approach and landing capability for military aircraft using an Embedded GPS/INS (EGI) system**

Elchynski, Joseph; Kirkland, Jeff (Honeywell, Inc., Clearwater, FL); Conner, Jim (Honeywell, Inc., Minneapolis, MN) In: IEEE 1998 Position Location and Navigation Symposium, Palm Springs, CA, Apr. 20-23, 1998, Proceedings (A99-11151 01-32), Piscataway, NJ, Institute of Electrical and Electronics Engineers, Inc., 1998, p. 487-494. 1998

**Abstract**

Honeywell is engaged in the research and development of a Precision Approach and Landing (PAL) capability for the EGI airborne navigation system. This PAL EGI approach guidance is augmented with differential corrections from a local area DGPS Satellite Landing System (SLS) ground station. The primary PAL EGI design goals are to meet military mission requirements, be interoperable with commercial airport SLS ground stations, and be compatible with existing aircraft avionics. Military requirements are being tracked via the Joint Precision Approach And Landing System (JPALS) program and civilian interoperability requirements are gleaned through the FAA's Local Area Augmentation System (LAAS) program. The EGI's configurable avionics interface can deliver approach guidance to the cockpit via existing ILS-based avionics or can be tailored for unique applications. The capabilities of the PAL EGI are described, including unique military characteristics that are only possible when the EGI is authorized for Precise Positioning Service, and standard LAAS capabilities and technical performance. Finally, PAL EGI test results are described.

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**Development of advanced approach and departure procedures. Failure scenarios**

Erkelens, L. J. J.; Vandronkelaar, J. H. National Aerospace Lab., Amsterdam (Netherlands). Sep., 1994, 18P. Report Number: PB95-198123; NLR-TP-93348-U

**Abstract**

Under a joint contract awarded by the Federal Aviation Administration (FAA) and the Netherlands Department of Civil Aviation (RLD), a flight simulator program was carried out on National Aerospace Laboratory's (NLR's) Research Flight Simulator (RFS) with 19 airline crews to evaluate various test scenarios concerning curved approaches and departures. The test program was flown under full Microwave Landing System (MLS) guidance with a simulated Boeing 747-200 aircraft. The scenarios included procedures for both to New York Area (John F.

Kennedy International and La Guardia Airports) and Amsterdam International Airport Schiphol. Four curved approaches and two MLS departures have been evaluated. Crew ability to detect insidious failures and to respond to them were investigated. Crew performance and perception data were also measured in case of a simulated failure of the flight management computer during execution of a curved approach. The workload during a one-engine inoperative flight was also evaluated.

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#### **(The) development of flight deck displays**

Stringer, F. S. (Royal Aircraft Establishment, Farnborough, Hants., England) *Journal of Navigation* (ISSN 0020-3009), vol. 37, May 1984, p. 217-231. May, 1984

##### **Abstract**

The evolution of controls and displays in military and civil fixed-wing aircraft is reviewed, and the development of flight instruments up to the present high degree of automation is traced. Topics covered include blind-flying and all-weather instruments, vhf communications, flight automation, and the total civil flight deck. A consideration of military aircraft includes color CRT head-up displays, voice control and voice warning, and navigation systems.

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#### **Early flight test experience with Cockpit Displayed Traffic Information (CDTI)**

Abbott, T. S.; Moen, G. C. (Army Res. and Technol. Labs., Hampton, Va.); Person, L. H., JR.; Keyser, G. L., JR.; Yenni, K. R.; Garren, J. F., JR. National Aeronautics and Space Administration. Langley Research Center, Hampton, VA. Feb., 1980, 31P. Report Number: NASA-TM-80221; AVRADCOM-TR-80-B-2 Contract Number: DA PROJ. 1L2-62209-AH-76; RTOP 534-04-13-57

##### **Abstract**

Coded symbology, based on the results of early human factors studies, was displayed on the electronic horizontal situation indicator and flight tested on an advanced research aircraft in order to subject the coded traffic symbology to a realistic flight environment and to assess its value by means of a direct comparison with simple, un-coded traffic symbology. The tests consisted of 28 curved, decelerating approaches, flown by research-pilot flight crews. The traffic scenarios involved both conflict-free and blunder situations. Subjective pilot commentary was obtained through the use of a questionnaire and extensive pilot debriefing sessions. The results of these debriefing sessions group conveniently under either of two categories: display factors or task performance. A major item under the display factor category was the problem of display clutter. The primary contributors to clutter were the use of large map-scale factors, the use of traffic data blocks, and the presentation of more than a few aircraft. In terms of task performance, the cockpit displayed traffic information was found to provide excellent overall situation awareness.

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#### **Effect of display size on utilization of traffic situation display for self-spacing task (transport aircraft)**

Abbott, T. S.; Moen, G. C. (Army Aviation Research and Development Command, Hampton, Va.) National Aeronautics and Space Administration. Langley Research Center, Hampton, VA. Aug., 1981, 30P. Report Number: NASA-TP-1885; L-14418; AVRADCOM-TR-81-B-4 Contract Number: DA PROJ. 1L2-62209-AH-76; RTOP 505-04-13-5

##### **Abstract**

The weather radar cathode ray tube (CRT) is the prime candidate for presenting cockpit display of traffic information (CDTI) in current, conventionally equipped transport aircraft. Problems may result from this, since the CRT size is not optimized for CDTI applications and the CRT is not in the pilot's primary visual scan area. The

impact of display size on the ability of pilots to utilize the traffic information to maintain a specified spacing interval behind a lead aircraft during an approach task was studied. The five display sizes considered are representative of the display hardware configurations of airborne weather radar systems. From a pilot's subjective workload viewpoint, even the smallest display size was usable for performing the self spacing task. From a performance viewpoint, the mean spacing values, which are indicative of how well the pilots were able to perform the task, exhibit the same trends, irrespective of display size; however, the standard deviation of the spacing intervals decreased (performance improves) as the display size increased. Display size, therefore, does have a significant effect on pilot performance.

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#### **Effect of lead-aircraft ground-speed on self-spacing performance using a cockpit display of traffic information**

Kelly, J. R. National Aeronautics and Space Administration. Langley Research Center, Hampton, VA. Oct. , 1983 , 50P. Report Number: NASA-TP-2194; L-15402; NAS 1.60:2194 Contract Number: RTOP 505-35-23-03

##### **Abstract**

A simulator investigation was conducted to determine the effect of the lead-aircraft ground-speed quantization level on self-spacing performance using a Cockpit Display of Traffic Information (CDTI). The study utilized a simulator employing cathode-ray tubes for the primary flight and navigation displays and highly augmented flight control modes. The pilot's task was to follow, and self-space on, a lead aircraft which was performing an idle-thrust profile descent to an instrument landing system (ILS) approach and landing. The spacing requirement was specified in terms of both a minimum distance and a time interval. The results indicate that the ground-speed quantization level, lead-aircraft scenario, and pilot technique had a significant effect on self-spacing performance. However, the ground-speed quantization level only had a significant effect on the performance when the lead aircraft flew a fast final approach.

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#### **Effects of a moving map display on pilot performance on instrument approach procedures**

Hannon, Daniel J. (Battelle Memorial Inst., Columbus, OH) In: SAE 1994 Transactions, Journal of Aerospace. Section 1 - Vol. 103 (A96-40177 11-31), Warrendale, PA, Society of Automotive Engineers, Inc., 1995,p. 2141-2149. 1995 Report Number: SAE-942148

##### **Abstract**

Three different electronic displays of instrument approach procedure (IAP) charts were tested in a flight simulator. The first display format emulated existing paper charts. The second added dynamic information of ownship position to the first format. The third contained only tabular information of waypoint names, distance, headings, and altitudes. Pilots flew two approaches with each electronic display and two with paper IAP charts. Performance and subjective measures were collected. No significant differences were found on performance measures for the different display conditions. Strong subjective preferences were found for the second display format. The results are discussed in terms of the implications for the design of electronic displays of instrument approach procedure charts.

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#### **Effects of curved approach paths and advanced displays on pilot scan patterns**

Harris, R. L., SR.; Mixon, R. W. National Aeronautics and Space Administration. Langley Research Center, Hampton, VA. Place of Publication: Washington May , 1981 , 29P. Report Number: NASA-TP-1846; L-14229 Contract Number: RTOP 505-35-23-01

## Abstract

The effect on pilot scan behavior of both advanced cockpit and advanced maneuvers was assessed. A series of straight-in and curved landing approaches were performed in the Terminal Configured Vehicle (TCV) simulator. Two comparisons of pilot scan behavior were made: (1) pilot scan behavior for straight-in approaches compared with scan behavior previously obtained in a conventionally equipped simulator, and (2) pilot scan behavior for straight-in approaches compared with scan behavior for curved approaches. The results indicate very similar scanning patterns during the straight-in approaches in the conventional and advanced cockpits. However, for the curved approaches pilot attention shifted to the electronic horizontal situation display (moving map), and a new eye scan path appeared between the map and the airspeed indicator. The very high dwell percentage and dwell times on the electronic displays in the TCV simulator during the final portions of the approaches suggest that the electronic attitude direction indicator was well designed for these landing approaches.

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## Emerging cockpit technologies for free flight

Chang, G. C. (1996). In Proceedings of 15th AIAA/IEEE Digital Avionics Systems Conference, Atlanta, GA. Record (A96-45660 12-01).

## Abstract

Successful implementation of the free flight concept requires new technologies and associated control procedures and standards for the flight crew, the air traffic service provider, and, where applicable, the dispatcher. This paper explores key cockpit technologies and procedures that enhance aviation safety and, at the same time, are cockpit-enabling technologies for free flight. These enabling technologies are integrated through two complementary operational concepts known as Flight Operations and Air Traffic Management Integration and Situational Awareness for Safety (SAS), with due consideration given to human factors. These two concepts, along with their supporting avionics, data links, and ground-side air traffic and flight information service infrastructure, make free flight a distinct technical possibility

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## Enhancing vertical navigation performance in glass-cockpit aircraft

McCrobie, Daniel (Honeywell Air Transport Systems, Phoenix, AZ); Alkin, Martin (Federal Express Corp., Memphis, TN); Sherry, Lance (Honeywell Air Transport Systems, Phoenix, AZ); Feary, Michael (San Jose State Univ., CA); Polson, Peter (Colorado, Univ., Boulder); Palmer, Everett (NASA, Ames Research Center, Moffett Field, CA) In: International Symposium on Aviation Psychology, 9th, Columbus, OH, Apr. 27-May 1, 1997, Proceedings. Vol. 1 (A98-28868 07-53), Columbus, OH, Ohio State University, 1997, p. 434-439. 1997

## Abstract

A survey was given to 550 pilots who currently fly 'glass-cockpit' aircraft. A total of 203 surveys were returned indicating pilots' preferences for flying with the automation, their use of vertical navigation, their ability to use and interpret displays, and their thoughts on training. Survey results indicated that pilots do not use the full automation capabilities over the entire course of a mission. Pilots also reported that a variety of automation surprises were seen on the modern flight deck. The survey allowed pilots to comment on the current design of the cockpit and training procedures. Design implications are discussed.

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### **(An) evaluation of approach and landing factors influencing airport safety**

Khatwa, R.; Roelen, A. L.; Karwal, A. K. (National Aerospace Lab., Amsterdam, Netherlands); Enders, J. H. (Enders Associates, Bethesda, MD); Dodd, R.; Tarrel, R. (Records Management Systems, Fairfax, VA) In: Best practices and processes for safety; Proceedings of the Joint Meeting of the Flight Safety Foundation 49th Annual International Air Safety Seminar, IFA 26th International Conference and IATA, Dubai, United Arab Emirates, Nov. 11-14, 1996 (A97-29699 07-03), Alexandria, VA, Flight Safety Foundation, 1997, p. 316-326.1997

#### **Abstract**

This study examines factors that influence approach and landing safety at principal international airports, especially as regards the influence on risk of fully-functioning precision terminal approach and guidance equipment. The objective is to quantify the degree to which these factors are associated with the risk of an accident. Accident and movement data for 557 ICAO Principal Airports for decade 1984-1993 were evaluated for the risk analysis. The accident sample comprised 132 hull loss occurrences. The study concludes that precision approaches confer a risk advantage of about 5 over non-precision approaches globally, absent other factors. The study also concludes that, when stratified according to ICAO region, the risk increase associated with flying non-precision approaches compared with flying precision approaches varies from three-fold to nearly eight-fold. The lack of Terminal Approach Radar (TAR) increased risk among the study population three-fold compared to approaches with TAR present. However, this threefold increase in risk may be attributed to the risk associated with non-precision approaches as in certain regions a correlation exists between the presence of radar and the presence of precision approach aids. Data are also presented that quantify the influence of high terrain, approach lighting and published standard instrument arrival routes on safety.

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### **Evaluation of Approach and Landing Factors Influencing Airport Safety**

Khatwa, R. (National Aerospace Lab., Flight Div., Amsterdam, Netherlands); Roelen, A. L. (National Aerospace Lab., Flight Div., Amsterdam, Netherlands); Karwal, A. K. (National Aerospace Lab., Flight Div., Amsterdam, Netherlands); Enders, J. H. (National Aerospace Lab., Flight Div., Amsterdam, Netherlands); Dodd, R. (National Aerospace Lab., Flight Div., Amsterdam, Netherlands) NASA no. 19980017673. Mar. , 1996 Report Number: NASA no. 19980017673; PB97-204788; NLR-TP-96221-U

#### **Abstract**

This exploratory study examined some of the factors that influence approach and landing safety at principal international airports, especially as regards the influence on risk of fully-functioning precision terminal approach and guidance equipment. The objective was to quantify the degree to which these factors are associated with the risk of an accident. Accident and movement data for 557 ICAO Principal Airports for decade 1984-1993 were evaluated for the risk analysis. The accident sample comprised 132 hull loss occurrences. The study concludes that precision approaches confer a risk advantage of about five over non-precision approaches absent other factors on a world-wide basis.

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### **Evaluation of near-term applications for ADS-B/CDTI implementation**

Olmos, Baltazar O.; Mundra, Anand; Cieplak, James J.; Domino, David A.; Stassen, Hans P. (MITRE Center for Advanced Aviation System Development, Alexandria, VA) AIAA and SAE, 1998 World Aviation Conference, Anaheim, CA, Sept. 28-30, 1998, 13 p.. Sep. , 1998 Report Number: AIAA Paper 98-5555; SAE Paper 985555

#### **Abstract**

Two studies are reported that evaluated near-term terminal and oceanic applications for ADS-B/CDTI implementation. A brief description of each application is provided with an emphasis on how a Cockpit Display of

Traffic Information (CDTI) capability might help to enhance their operations. In the first experiment, 16 line pilots flew eight terminal visual approach scenarios with target speed cues and ground track vectors presented on a CDTI. Performance measures revealed closer spacing with the CDTI and a safety benefit with respect to enhanced awareness of proximate traffic speed reductions. In the second experiment, eight additional line pilots flew six oceanic scenarios using a CDTI feature set similar to that used in the first experiment. The scenarios were based on the current In-Trial Climb/In-Trail Descent (ITC/ITD) oceanic procedures and were modified slightly to take advantage of potential CDTI capabilities. The implications of these findings with respect to the current NAS are discussed.

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#### **Evaluation of pathway symbology used to land from curved approaches with varying visibility conditions**

Reising, J., Liggett, K., Kustra, T., and Snow, M. (1998). In Proceedings of 42nd Annual Human Factors and Ergonomics Meeting, Chicago, IL. Vol. 1. p1-5.

##### **Abstract**

Global Positioning System technology has the potential to revolutionize both commercial and military aircraft landing procedures. It will enable pilots to fly complex, curved approaches rather than the more simple straight-in approaches necessitated by the Instrument Landing System used at most large airports. To complement this technology, Head-Up Display pathway symbology was developed for use in the aircraft to help pilots stay on course during these complex landings. Thirteen Air Force pilots used this pathway symbology in a simulator to land under Visual Meteorological, Partial Instrument Meteorological, and Full Instrument Meteorological visibility conditions. Deviations from commanded flight path, as well as lateral and longitudinal deviations from a desired runway touchdown point, were measured. Results indicated that landing performance was acceptable for all pilots and functionally equivalent in all weather conditions. Results of this study suggest that pathway symbology could provide the cues necessary to successfully fly complex, curved approaches to landing. In addition, the merits of using Equivalency Analysis, rather than traditional Analysis of Variance in testing for performance differences are discussed.

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#### **Evaluation of scheduling methods for multiple runways**

Bolender, Michael A.; Slater, G. L. (Cincinnati, Univ., OH) AIAA, Guidance, Navigation and Control Conference, San Diego, CA, July 29-31, 1996, 12 p.. Jul. , 1996 Report Number: AIAA Paper 96-3719 Contract Number: NCC2-669

##### **Abstract**

Several scheduling strategies are analyzed in order to determine the most efficient means of scheduling aircraft when multiple runways are operational and the airport is operating at different utilization rates. The study compares simulation data for two and three runway scenarios to results from queuing theory for an M/D/n queue. The direction taken, however, is not to do a steady-state, or equilibrium, analysis since this is not the case during a rush period at a typical airport. Instead, a transient analysis of the delay per aircraft is performed. It is shown that the scheduling strategy that reduces the delay depends upon the density of the arrival traffic. For light traffic, scheduling aircraft to their preferred runways is sufficient; however, as the arrival rate increases, it becomes more important to separate traffic by weight class. Significant delay reduction is realized when aircraft that belong to the heavy and small weight classes are sent to separate runways with large aircraft put into the 'best' landing slot.

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### **(An) evaluation of software tools for the design and development of cockpit displays**

Ellis, Thomas D., JR. (Unisys Corp.; NASA, Langley Research Center, Hampton, VA) National Aeronautics and Space Administration. Langley Research Center, Hampton, VA. In: AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers (A93 52651 23-09) Place of Publication: Washington Publisher: American Institute of Aeronautics and Astronautics 1993 Report Number: AIAA PAPER 93-3593

#### **Abstract**

The use of all-glass cockpits at the NASA Langley Research Center (LaRC) simulation facility has changed the means of design, development, and maintenance of instrument displays. The human-machine interface has evolved from a physical hardware device to a software-generated electronic display system. This has subsequently caused an increased workload at the facility. As computer processing power increases and the glass cockpit becomes predominant in facilities, software tools used in the design and development of cockpit displays are becoming both feasible and necessary for a more productive simulation environment. This paper defines LaRC requirements of a display software development tool and compares two available applications against these requirements. As a part of the software engineering process, these tools reduce development time, provide a common platform for display development, and produce exceptional real-time results.

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### **(The) Final Approach Spacing Tool (FAST)**

Slattery, Rhonda (NASA Ames Research Center, Moffett Field, CA United States) NASA no. 19980073307. Proceedings of the NASA First Wake Vortex Dynamic Spacing Workshop. Nov. , 1997 Report Number: NASA no. 19980073307

#### **Abstract**

The Final Approach Spacing Tool (FAST) is a decision support tool for terminal area (TRACON) air traffic controllers. FAST utilizes 4D trajectory synthesis, human performance modeling, and a graphical user interface to plan and advise efficient, conflict-free aircraft trajectories for arrival traffic. It increases airport capacity, reduces arrival delays, and reduces controller workload by issuing: sequence and runway advisories ("Passive" FAST) and speed and heading advisories ("Active" FAST). This paper discusses in detail the architecture of the system and operational tests done on the system.

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### **Flight investigation of cockpit-displayed traffic information utilizing coded symbology in an advanced operational environment**

Abbott, T. S.; Moen, G. C.; Person, L. H., JR.; Keyser, G. L., JR.; Yenni, K. R.; Garren, J. F., JR. National Aeronautics and Space Administration. Langley Research Center, Hampton, VA. Jul. , 1980 , 31P. Report Number: NASA-TP-1684; AVRADCOM-TR-80-B-4; L 13584 Contract Number: DA PROJ. 1L2-62209-AH-76; RTOP 534-04-13-57

#### **Abstract**

Traffic symbology was encoded to provide additional information concerning the traffic, which was displayed on the pilot's electronic horizontal situation indicators (EHSI). A research airplane representing an advanced operational environment was used to assess the benefit of coded traffic symbology in a realistic work-load environment. Traffic scenarios, involving both conflict-free and conflict situations, were employed. Subjective pilot commentary was obtained through the use of a questionnaire and extensive pilot debriefings. These results grouped conveniently under two categories: display factors and task performance. A major item under the display factor

category was the problem of display clutter. The primary contributors to clutter were the use of large map-scale factors, the use of traffic data blocks, and the presentation of more than a few airplanes. In terms of task performance, the cockpit-displayed traffic information was found to provide excellent overall situation awareness. Additionally, mile separation prescribed during these tests.

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**Flight Safety Foundation Approach-and-Landing Accident Reduction Task Force analysis of critical factors during approach and landing in accidents and normal flight – Data Acquisition and Analysis Working Group final report.**

Khatwa, R., and Helmreich, R. (1999). In Proceedings of World Aviation Conference, San Francisco, CA: AIAA Paper 99-5587, SAE Paper 1999-01-587.

**Abstract**

The final report of the Data Acquisition and Analysis Working Group of the Flight Safety Foundation Approach-and-Landing Accident Reduction (ALAR) Task Force contains data that may lead to the identification and/or resolution of approach-and-landing safety issues. Presented are high-level analysis of 287 fatal accidents; detailed case studies of 76 accidents and serious incidents; and the assessment of key crew behavioral markers isolated in the occurrences and in the line audits of about 3300 flights. Recommendations were derived from the results of the data analyses for specific industry groups: regulatory authorities, operators, flight crews, air traffic services, controllers, airport authorities, accident-investigation bodies, and airplane and equipment manufacturers.

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**Flight test evaluation of advanced symbology for general aviation approach to landing displays**

Downing, D. R.; Bryant, W. H.; Yenni, K. R. (NASA, Langley Research Center, Hampton, VA) National Aeronautics and Space Administration. Langley Research Center, Hampton, VA. American Institute of Aeronautics and Astronautics, Aircraft Systems and Technology Conference, Dayton, OH, Aug. 11-13, 1981, 9 p. Aug. , 1981 Report Number: AIAA PAPER 81 1643

**Abstract**

This paper describes a set of flight test experiments which were designed to evaluate the relative utility of candidate displays with advanced symbology for General Aviation IFR operations in the terminal area. This symbology was previously evaluated as part of the NASA Langley Research Center's Terminal Configured Vehicle Program for use in commercial airlines. The advanced symbology included vehicle track-angle, flight path angle and a perspective representation of the runway. These symbols were selectively drawn on a CRT display along with the roll attitude, pitch attitude, localizer-deviation and glide slope deviation. In addition to the CRT display, the instrument panel contained standard turn and bank, altimeter, rate of climb, airspeed, heading and engine instruments. The symbology was evaluated using tracking performance and pilot subjective ratings for an ILS capture and tracking task.

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**Four-D navigation in terminal zones: An automatic control problem (speed control for aircraft approach spacing)**

Pelegrin, M. J. Ecole Nationale Supérieure de l'Aéronautique, Toulouse (France). In AGARD Plans and Develop. for Air Traffic Systems 25 p (SEE N76-23191 14-04) Feb. , 1976



## **Abstract**

It is shown that, if a velocity profile is imposed upon the plane and controlled along a selected approach path, it is possible to limit the deviation from the computed arrival time of the plane at the ILS entry gate. Two simulation programs, a fast time one and one in real time, determine and control the optimum 4-D trajectory. The first results show that the accuracy of the simulation need not be very great; thus, the extra computing ground capacity is fairly limited. It can also be shown that an accurate descent trajectory is no problem for an aircraft equipped with an automatic throttle command. Moreover, a head-up display that gives the optimum glide slope angle allows a very accurate control of the plane along its longitudinal axis.

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## **Free flight in the terminal area - Where real capacity improvements can be made**

Corwin, Bill (Honeywell Technology Center, Minneapolis, MN) In: International Symposium on Aviation Psychology, 9th, Columbus, OH, Apr. 27-May 1, 1997, Proceedings. Vol. 2 (A98-29016 07-53), Columbus, OH, Ohio State University, 1997, p. 900-905. 1997

## **Abstract**

This paper examines the nature of airspace congestion within the terminal area, particularly with regard to other than 'fair weather' conditions, and examines various technologies and procedural changes that can increase airspace capacity and reduce delay. The role of free flight in such improvements is considered. A candidate fix is proposed for the case of parallel approaches in the terminal area.

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## **Functional categories for human-centered flight deck design**

Abbott, T. S. (NASA, Langley Research Center, Hampton, VA); Rogers, W. H. (Bolt, Beranek & Newman; NASA, Langley Research Center, Hampton, VA) In: AIAA/IEEE Digital Avionics Systems Conference, 12th, Fort Worth, TX, Oct. 25-28, 1993, Proceedings (A94-23499 06-01), New York, Institute of Electrical and Electronics Engineers, Inc., 1993, p. 66-74. 1993

## **Abstract**

A 'human-centered', systems-oriented approach to the design of advanced civil aircraft flight decks is required to improve their overall safety. An initial step in such an approach involves the definition of primary flight deck functions required to support the aircraft's mission goals, allowing the design team to evaluate candidate concepts according to functional requirements. A set of such functional categories is here presented which encompasses the four 'first-level' functions of flight management, communications management, systems management, and task management.

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## **Future flight decks**

Arbuckle, P. D.; Abbott, Terence S.; Schutte, Paul C. (NASA, Langley Research Center, Hampton, VA); Abbott, Kathy H. (FAA, Washington, DC) ICAS, Congress, 21st, Melbourne, Australia, Sept. 13-18, 1998, 12 p.. Sep. , 1998 Report Number: ICAS Paper 98-1,9,3

## **Abstract**

The evolution of commercial transport flight deck configurations over the past 20-30 years and expected future developments is described. Key factors in the aviation environment are identified that the authors expect will significantly affect flight deck designers. One of these is the requirement for commercial aviation accident rate

reduction, which is probably required if global commercial aviation is to grow as projected. Other factors include the growing incrementalism in flight deck implementation, definition of future airspace operations, and expectations of a future pilot corps that will have grown up with computers. Future flight deck developments are extrapolated from observable factors in the aviation environment, recent research results in the area of pilot-centered flight deck systems, and by considering expected advances in technology that are being driven by other than aviation requirements. The authors hypothesize that revolutionary flight deck configuration changes will be possible with development of human-centered flight deck design methodologies that take full advantage of commercial and/or entertainment-driven technologies. (26 Refs.)

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#### **Future terminal area systems**

Jorgensen, P. A. (Selenia-Industrie Elettroniche Associate S.p.A., Rome, Italy) (International Federation of Air Traffic Controllers' Associations, West European Conference, Rome, Italy, Nov. 12-14, 1981.) *The Controller*, vol. 21, May 1982, p. 34, 35. May, 1982

#### **Abstract**

The development of a terminal area computer system able to interface with existing flight management systems is discussed, and this type of system is intended to provide greater fuel conservation and air space capacity, with improved safety during the descent phase of flights. The system must be able to forecast a suitable approach routing, which will allow for a continuous descent of each aircraft, while also providing optimal distribution. Utilizing such a system, a controller would concentrate on monitoring the separation between the aircraft and would only rarely need to intervene in the landing process. Studies are being conducted to determine optimum approach patterns for such a system with regard to fuel conservation, safety and airspace capacity. A graph of the actual measured fuel consumption found for three different patterns - the standard descent profile, the low drag/low power approach, and a low drag/delayed flaps approach - is presented.

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#### **Human factors considerations of aircraft displays**

Wentz, Charles P. (Kent State Univ., OH); Schnell, Thomas; Zwahlen, Helmut T. (Ohio Univ., Athens) In: 1998 Advances in Aviation Safety Conference and Exposition, Daytona Beach, FL, Apr. 6-8, 1998, Proceedings (A98-41351 11-03), Warrendale, PA, Society of Automotive Engineers, Inc., 1998, p. 193-208. 1998 Report Number: SAE Paper 981237

#### **Abstract**

In current general aviation aircraft it is not uncommon to find very old designs of electromechanical instruments next to state-of-the-art pixel-based displays. A number of these instruments appear to be inadequate from a legibility, interpretability, and operational point of view. This paper contains a review of the relevant display reading performance literature. The key principles (luminance contrast and critical detail) of display legibility are demonstrated using a general aviation altimeter as an example. A particular safety concern is the legibility of the pressure display found on typical altimeter instruments. (45 Refs.)

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#### **Human factors considerations of the perception of colour in the airborne environment**

Gibson, C. P.; Laycock, J. Royal Aircraft Establishment, Farnborough (England). In AGARD Advan. Avionics and the Mil. Aircraft Man/Machine Interface 9 p (SEEN83-18257 08-54) Jul., 1982

## Abstract

The various CRT technologies in relation to the CIE system of color measurement and the applications and possible pitfalls associated with the use of color as a means of encoding information are discussed. It is suggested that CRTs will become the prime, and certainly the most flexible, display medium in the modern cockpit. The human factors aspects of the use of color are crucial if optimum advantage is to be made of this coding dimension since many areas remain relatively unexplored. The basic mechanisms, and some of the anomalies, of color perception are presented and illustrated. Psychological effects such as the change of perceived hue with luminance, the perceived changes caused by simultaneous color contrast and the effects of chromatic adaptation are outlined.

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## **(The) influence of the design of displays on cockpit workload**

Holmes, R. H. Marconi Avionics Ltd., Rochester (England). Airborne Display Div. In AGARD High-Speed, Low-Level Flight 10 p (SEE N80-29990 20-51) Mar. , 1980

## Abstract

The problems involved in designing display and controls for high speed low-level aircraft are discussed with the emphasis on the reduction of cockpit workload. Some modern display techniques are also described.

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## **Information and display requirements for independent landing monitors (Final Report, Jul. 1974 - Jul. 1975)**

Karmarker, J. S.; Sorensen, J. A. Systems Control, Inc., Palo Alto, CA.

Place of Publication: Washington Publisher: NASA Aug. , 1976 , 171P. Report Number: NASA-CR-2687 Contract Number: NAS 1-13490

## Abstract

The ways an Independent Landing Monitor (ILM) may be used to complement the automatic landing function were studied. In particular, a systematic procedure was devised to establish the information and display requirements of an ILM during the landing phase of the flight. Functionally, the ILM system is designed to aid the crew in assessing whether the total system (e.g., avionics, aircraft, ground navigation aids, external disturbances) performance is acceptable, and, in case of anomaly, to provide adequate information to the crew to select the least unsafe of the available alternatives. Economically, this concept raises the possibility of reducing the primary auto-land system redundancy and associated equipment and maintenance costs. The required level of safety for the overall system would in these cases be maintained by upgrading the backup manual system capability via the ILM. A safety budget analysis was used to establish the reliability requirements for the ILM. These requirements were used as constraints in devising the fault detection scheme. Covariance propagation methods were used with a linearized system model to establish the time required to correct manually perturbed states due to the fault. Time-to-detect and time-to-correct requirements were combined to devise appropriate altitudes and strategies for fault recovery.

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## **(The) information content of cockpit displays**

Ritchie, Malcolm L. In: NAECON 94; Proceedings of the IEEE 1994 National Aerospace and Electronics Conference, Dayton, OH, May 23-27, 1994, Vol. 2 (A95-27710 06-66), New York, Institute of Electrical and Electronics Engineers, Inc., 1994, p. 646-650. 1994

## Abstract

Cockpit displays have been described by name and by pictures or diagrams in which each indicator element is named. The names of the elements themselves are frequently not precisely defined. Within a single display and among the several displays on a panel it has been difficult to identify redundancy and equivalence of information. This paper presents a system of definitions and notation of display information elements. The system is based on a synthesis of (1) engineering definitions related to equations of motion and (2) human performance data which relate equivalence and sufficiency of displayed parameters.

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#### **Input of ATM on future flight deck design**

Jorna, P. (1995). In Proceedings of the 21st Conference of the European Association for Aviation Psychology, Dublin, Ireland. Record (A95-40158 11-53).

##### **Abstract**

Air traffic management concepts aim at increasing air space capacity and throughput by more accurate planning, navigation, and the use of time-based operations, effectively creating a 4D environment. Pilots and controllers are still regarded to be critical components of the future system and they should be supported by optimized man-machine interfaces to assure adequate performance. Multiple strategies can be identified in accomplishing the challenge. The roles of pilot and the tasks allocated to human operators will change. With more aircraft, safety also needs to be enhanced drastically. Both requirements will influence future flight deck design. Two possible cockpit extremes are identified and discussed.

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#### **Interactive design tool for cockpit controls and displays development**

Qualls, G. (Boeing Military Airplane Co., Wichita, KS) AIAA, AHS, and ASEE, Aircraft Systems, Design and Technology Meeting, Dayton, OH, Oct. 20-22, 1986. 7 p. Oct. , 1986 Report Number: AIAA PAPER 86-2735

##### **Abstract**

The architecture of the Virtual Avionics Driver System (VADS) utilized for the development of interactive controls and displays for a crew station is described. The system consists of a portable, user programmable control and display console and a maintenance terminal. The VADS employs a user definable cockpit control language and state tables containing data on the functionality of operator actions. The functions of the switch, task, and data tables are discussed. The hardware of the system performs state table sequencing, command processing, and input/output.

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#### **In-trail following during profile descents with a cockpit display of traffic information.**

Chappell, S. L., and Palmer, E. (1981). In Proceedings of the 1st Symposium on Aviation Psychology, Columbus, OH. Record (A82-46251 23-53) p 94-105.

##### **Abstract**

Four line pilots performed simulator flights of 747s on different air routes in conditions of following other aircraft while maintaining a specified temporal flight interval separation. The flights were made in the heading-select mode of the autopilot, and the pitch wheel or altitude select/hold mode with the throttle on manual. A cockpit display of traffic information (CDTI) on a CRT was presented in front of the throttles. A VOR radial with dotted centerlines and sidebands representing 3 km intervals was displayed, along with scales of distance depending on altitude. Traffic information was updated every four seconds. Simulated flights began at cruise and followed a standard

profile descent, and traffic following intervals of 60, 80, 120, and 140 seconds were presented in different trials. Results indicated that a CDTI was sufficient instrumentation for trailing other aircraft, with low error rates up to the point of landing preparations.

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### **In-trail spacing dynamics of multiple CDTI-equipped aircraft queues**

Kelly, J. R. and Abbott, T. S. (1984). NASA Technical Memorandum 85699, National Aeronautics and Space Administration.

#### **Abstract**

One of the potential applications of a Cockpit Display of Traffic Information (CDTI) is self-spacing wherein a pilot can acquire and maintain a specified in-trail interval on a lead aircraft. An assumption behind this application is that pilots using CDTI should be able to achieve more consistent spacing performance than the present Air Traffic Control concept (which employs ground-controlled spacing techniques) and, hence, runway throughput could be increased. Along with this benefit, however, comes the question of whether dynamic oscillations would occur, similar to the "accordion" effect seen with a queue of automobiles in stop-and-go traffic.

In order to gain some insight into this potential problem, a brief experiment was conducted with the Transport Systems Research Vehicle (TSRV) ground-based simulator equipped with a CDTI which presented the position of other aircraft in the area. Three simulation sessions were conducted wherein queues of up to nine aircraft were built by recording successive approaches flown in the simulator and using this recording as the source for traffic data on each subsequent approach. Each aircraft was therefore equipped with a CDTI which the pilot used to self-space on the proceeding aircraft. The aircraft crews were rotated to ensure that the pilots had no prior knowledge of the behavior of the lead aircraft they would be following. Two different spacing criteria were employed: a constant time predictor criterion and a constant time delay criterion. The experiment failed to uncover any dynamic oscillatory tendencies in queues of seven to nine aircraft.

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### **Investigating interruptions – An example from the flight deck**

Latorella, K. A. (1996). In Proceedings of the 40th Annual Meeting of the Human Factors and Ergonomics Society, Santa Monica, CA (p 249-253).

#### **Abstract**

This study investigates an aspect of multiple-task management, interruption management, in an operational context. Fourteen commercial airline pilots each performed 16 approaches in a simulated commercial flight deck. ATC clearances interrupted subjects as they performed three procedures during these approaches. Common ATC interruptions were found to be significantly disruptive to ongoing performance on the flight deck by producing significantly more procedure performance errors and increased flight path management activity. These results corroborate, for the flight deck, that which is true in laboratory experiments, and which is evidenced in aviation accident/incident reports.

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### **Jet transport flight operations using cockpit display of traffic information during instrument meteorological conditions: Simulation evaluation**

Williams, David H.; Wells, Douglas C. National Aeronautics and Space Administration. Langley Research Center, Hampton, VA. May , 1986 , 50P. Report Number: NASA-TP-2567; L 16091; NAS 1.60:2567 Contract Number: RTOP 505-67-01-01

#### **Abstract**

A simulation study was undertaken to evaluate flight operations using cockpit display of traffic information (CDTI) in a conventional jet transport aircraft. Eight two-person airline flight crews participated as test subjects flying simulated terminal area approach and departure operations under instrument meteorological conditions (IMC). A fixed-base cockpit simulator configured with a full complement of conventional electromechanical instrumentation to permit full workload operations was utilized. Traffic information was displayed on a color cathode-ray tube (CRT) mounted above the throttle quadrant in the typical weather radar location. A transparent touch panel overlay was utilized for pilot interface with the display. Air traffic control (ATC) simulation included an experienced controller and full party line radio environment for evaluation of pilot-controlled self-separation and traffic situation monitoring tasks. Results of the study revealed the CDTI to be well received by the test subjects as a useful system which could be incorporated into an existing jet transport cockpit. Crew coordination and consistent operating procedures were identified as important considerations in operational implementation of traffic displays. Cockpit workload was increased with active CDTI tasks. However, all test subjects rated the increase to be acceptable.

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### **Laws for the design of the universal cockpit displays**

Tannas, Lawrence E., Jr. (Tannas Electronics, Orange, CA) In: Cockpit displays V: Displays for defense applications; Proceedings of the Meeting, Orlando, FL, Apr. 15-17, 1998 (A99-12251 01 31), Bellingham, WA, Society of Photo-Optical Instrumentation Engineers (SPIE Proceedings. Vol. 3363), 1998, p. 108-111. 1998

#### **Abstract**

Major technological advances have occurred in the form of AMLCDs and electronics facilitating the design of the ultimate set of primary cockpit displays. Increased display design flexibility has led to a divergence, as evidenced in several new primary flight display designs. A set of 12 laws is proposed. The application of these laws will result in more cost-effective, reliable, and universal cockpit displays.

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### **Limitations of a holographic 3-D pixel projector for cockpit displays**

Kelly, Shawn L.; Robinson, Charles T. Wright Lab., Wright-Patterson AFB, OH. Aug. , 1991 , 5P. Report Number: AD-A241295; WL-TM-91-601

#### **Abstract**

One popular approach to increasing the combat capability of an aircraft is to reduce the pilot workload imposed by the interpretation of large quantities of displayed data into useful information. One facet of that workload is the mental exercise required by the pilot to visualize his dynamic three-dimensional (3-D) environment given data presented on two dimensional (2-D) cockpit displays. Therefore, it is a primary thrust of cockpit research to explore, develop, and test new display devices which can present data with the full 3-D image characteristics of stereopsis, full look-around, and ocular accommodation so that the magnitude of required mental visualization is greatly reduced.

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## **Major changes in sight for cockpit displays**

Fitzsimons, Bernard *Interavia/Aerospace World* (ISSN 0098-1592), vol. 49, no. 574, Jan. 1994, p. 46-49. Jan. , 1994

### **Abstract**

A development status and development trends evaluation are presented for Electronic Flight Instrument Systems (EFISs). It is noted that LCD-based displays are currently set to replace CRT-based systems, beginning with the B777 airliner; major developments in EFIS display design may be especially powerfully stimulated by the requirements for next-generation SST cockpits that incorporate wide field-of-view IR head-down displays depicting geographic and flight path information. An account is given of Boeing's Enhanced Situational Awareness System initiative, which foresees the displaying of runway hazards under all weather conditions by EFISs.

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## **(A) mathematical model of glide-slope perception in the visual approach to landing**

Galanis, George (DSTO, Air Operations Div., Melbourne, Australia); Jennings, Andrew; Beckett, Paul (Royal Melbourne Inst. of Technology, Australia) *International Journal of Aviation Psychology* (ISSN 1050-8414), vol. 8, no. 2, 1998, p. 83-101. 1998

### **Abstract**

A mathematical model of glide-slope perception is presented for the visual approach to landing when there is a visually impoverished scene. The perceptual process has been modeled as the weighted average of the geometric relations in the scene that provide glide-slope information, with weights being adjusted during the approach to minimize the uncertainty in glide-slope perception. The model suggests that the optimum combination of relations providing glide-slope information is dependent on the range from the runway threshold and that there is a relation between the handling qualities of aircraft or flight simulators and the adjustment of the weights.

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## **Modeling of the aircraft in-trail-following task during profile descent**

Goka, T., Sorensen, J. A., and Phatak, A. V. (1981). In *JPL Proceedings of the 17th Annual Conference on Manual Control* p 283-294 (SEE N82-13665 04-54).

### **Abstract**

The cockpit display of traffic information (CDTI) system concepts enable the pilot to observe the surrounding air traffic pattern. The impact of such a system is far reaching in terms of improved safety, pilot and controller workload, and aircraft fuel efficiency. One direct payoff is the ability to distribute the ATC workload to the pilot in such tasks as merging and spacing. The CDTI application of spacing approach aircraft in the terminal area is addressed. In-trail-following/CDTI experiments were performed using realistic cockpit simulators and profile descent approach scenarios. Based on collected experimental simulator data, pilot models were developed which include state estimation, decision making and flight control aspects. These models were coupled with models of aircraft and CDTI equipment to study the dynamic phenomena and stability of strings of aircraft along various approach patterns.

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### **Modeling to predict pilot performance during CDTI-based in-trail following experiments**

Sorensen, J. A. and Goka, T. (1984). In Proceedings of 22nd AIAA, Aerospace Sciences Meeting, Reno, NV. AIAA Paper 84-0517.

#### **Abstract**

A mathematical model was developed of the flight system with the pilot using a cockpit display of traffic information (CDTI) to establish and maintain in-trail spacing behind a lead aircraft during approach. Both in-trail and vertical dynamics were included. The nominal spacing was based on one of three criteria (Constant Time Predictor; Constant Time Delay; or Acceleration Cue). This model was used to simulate digitally the dynamics of a string of multiple following aircraft, including response to initial position errors. The simulation was used to predict the outcome of a series of in-trail following experiments, including pilot performance in maintaining correct longitudinal spacing and vertical position. The experiments were run in the NASA Ames Research Center multi-cab cockpit simulator facility. The experimental results were then used to evaluate the model and its prediction accuracy. Model parameters were adjusted, so that modeled performance matched experimental results. Lessons learned in this modeling and prediction study are summarized.

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### **Multi-function displays in the cockpit - A methodology for interface and interaction design**

Parush, A. (Israel Aircraft Industries, Ltd., Human Factors Engineering Dept., Lod) IN: International Symposium on Aviation Psychology, 4th, Columbus, OH, Apr. 27-30, 1987, Proceedings (A88-42927 17-53). Columbus, OH, Ohio State University, 1987, p. 37-43. 1987

#### **Abstract**

The basic principles involved in the interface and interaction methodology for the cockpit multifunction displays (MFDs) is discussed, with particular attention given to the MFDs which include only software-controlled keys. The proposed methodology presents a systematic process of identifying and mapping the correspondence between MFD functions and their spatial/visual labeling. Special consideration is given to the unique constraints and problems involved in the display format issues and interaction with various types of MFD's (e.g., the multidimensionality of MFD labels), the psychological aspects of the MFD problem, and the steps involved in the interface and interaction methodology.

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### **(The) mythology of first-come-first-serve landing order**

Welch, J. D. (MIT, Lexington, MA) IN: Radio Technical Commission for Aeronautics, Annual Assembly and Technical Symposium, Washington, DC, Dec. 4-6, 1989, Proceedings (A90-46390 21-04). Washington, DC, Radio Technical Commission for Aeronautics, 1989, p. 93 98. Research sponsored by FAA. 1989

#### **Abstract**

The problem of definitions is first discussed, pointing out that the first-come criterion ideally should be defined as early as possible in the terminal area. The various factors influencing landing time are analyzed, including wind as a key limitation to manual ATC systems. It is noted that only TRACON controllers can predict landing time with enough certainty, however, in high-demand situations, controllers cannot consistently arrange arriving aircraft in first-come-first-serve order at any phase in the landing process. The introduction of computer aids into the terminal air-traffic control routine is proposed, specifically, in the area of arrival sequencing; such techniques can be incorporated in the Advanced Automation System.

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### **New approach to the planning and control of air traffic in the terminal area**

Idris, Husni R.; Simpson, Robert W. (MIT, Cambridge, MA) In: AIAA Guidance, Navigation, and Control Conference and Exhibit, Boston, MA, Aug. 10-12, 1998, Collection of Technical Papers. Pt. 2 (A98-37001 10-63), Reston, VA, American Institute of Aeronautics and Astronautics, 1998, p. 957-970. 1998 Report Number: AIAA Paper 98-4292

#### **Abstract**

A new approach to the planning and control of the traffic in the terminal area is proposed which combines the path generation and conflict avoidance problems into one problem. The objective is to generate conflict-free paths for all aircraft in the terminal area in order to meet the given landing schedule at the runway. It is assumed that the given schedule guarantees the existence of such conflict-free paths; otherwise, the schedule needs to be revised accordingly. This paper presents the concept geometrically, and results in an algorithm which generates conflict-free paths for all aircraft simultaneously.

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### **(A) numerical simulation study to develop an acceptable wake encounter boundary for a B737-100 airplane**

Vicroy, Dan D.; Nguyen, Truc (NASA, Langley Research Center, Hampton, VA)  
In: AIAA Atmospheric Flight Mechanics Conference, San Diego, CA, July 29-31, 1996, Technical Papers (A96-35084 09-08), Reston, VA, American Institute of Aeronautics and Astronautics, 1996, p. 88-96. 1996 Report Number: AIAA Paper 96-3372

#### **Abstract**

NASA is conducting research with the goal of enabling safe improvements in the capacity of the nation's air transportation system. The wake-vortex upset hazard is an important factor in establishing the minimum safe spacing between aircraft during landing and take-off operations, thus impacting airport capacity. A batch simulation study was conducted to assess the sensitivity of various safe landing criteria in the development of an acceptable wake encounter boundary. A baseline 6-DOF simulation of a B737-100 airplane was modified to include a wake model and the vortex-induced forces and moments. The guidance and control input for the airplane was provided by an auto-land system. The wake strength and encounter geometry were varied. A sensitivity study was also conducted to assess the effects of encounter modeling methods and accuracy.

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### **Operational concepts for limited delegation of separation assurance to the cockpit**

Hoffman, E., Zeghal, K., Cloerec, A., Grimaud, I., and Nicolaon, J. (1999). In AIAA Guidance, Navigation, and Control Conference and Exhibit, Collection of Technical Papers, Vol. 1 p 325-334. Reston, VA.

#### **Abstract**

Following the EUROCONTROL ATM2000+ Strategy, this paper presents an investigation into delegation of separation assurance to the cockpit, as a near term application in managed airspace. Expected gains are mainly a reduction of controller workload together with the improvement of safety and flight efficiency. Two key constraints are driving the study. The first one relates to human acceptability: respect roles and work methods of controllers and pilots. It enables progressive confidence through incremental practice. The second constraint relates to technology: rely on minimum assumptions for surveillance facilities and equipment modification. For that purpose, the concept presented is designed according to two key points: limited delegation and flexible use of delegation. The overall

concept is presented, along with the phraseology and appropriate cockpit displays. Two major classes of application are considered: crossing and passing in en-route airspace, and sequencing in TMA (Terminal Maneuvering Area).

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### **Optimising height presentation for aircraft cockpit displays**

Jordan, C. S.; Croft, D.; Selcon, S. J.; Markin, H.; Jackson, M. (Defence Evaluation and Research Agency, Farnborough, United Kingdom) In: Imaging sciences and display technologies; Proceedings of the Conference, Berlin, Germany, Oct. 7-10, 1996 (A97-21326 04-35), Bellingham, WA, Society of Photo-Optical Instrumentation Engineers (SPIE Proceedings. Vol. 2949), 1996, p. 143-150. 1996

#### **Abstract**

An experiment was conducted to investigate the display symbology that most effectively conveys height information to users of head-down plan-view radar displays. The experiment also investigated the use of multiple information sources (redundancy) in the design of such displays. Subjects were presented with eight different height display formats. These formats were constructed from a control, and/or one, two, or three sources of redundant information. The three formats were letter coding, analog scaling, and toggling (spatially switching the position of the height information from above to below the aircraft symbol). Subjects were required to indicate altitude awareness via a four-key, forced-choice keyboard response. Error scores and response times were taken as performance measures. There were three main findings. First, there was a significant performance advantage when the altitude information was presented above and below the symbol to aid the representation of height information. Second, the analog scale, a line whose length indicated altitude, proved significantly detrimental to performance. No relationship was found between the number of redundant information sources employed and performance. The implications for future aircraft and displays are discussed in relation to current aircraft tactical displays and in the context of perceptual psychological theory.

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### **Past Wake Vortex Investigations and Dynamic Spacing Systems**

Spitzer, Edward A. (Federal Aviation Administration, Volpe National Transportation Systems Center, Cambridge, MA United States); Hallock, James N. (Federal Aviation Administration, Volpe National Transportation Systems Center, Cambridge, MA, United States); Burnham, David C. (Scientific and Engineering Solutions, Inc., Orleans, MA United States); Rudis, Robert P. (Federal Aviation Administration, Volpe National Transportation Systems Center, Cambridge, MA United States) NASA no. 19980073277. Proceedings of the NASA First Wake Vortex Dynamic Spacing Workshop. Nov. , 1997 Report Number: NASA no. 19980073277

#### **Abstract**

A history is given of the past research concerning wake vortex and dynamic spacing systems. Current research and vortex physics, safety and hazard definition are also presented.

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### **Perception of aircraft separation with pilot-preferred symbology on a cockpit display of traffic information**

O'Connor, S. (San Jose State Univ.); JAGO, S. (San Jose State Univ.); Baty, D.; Palmer, E. National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA. Sep. , 1980 , 16P. Report Number: NASA-TM-81172; A-8107 Contract Number: NSG-2269; RTOP 505-35-21

#### **Abstract**

The concept of a cockpit display of traffic information (CDTI) was developed for use in later full mission simulator evaluations of the CDTI concept. Pilots chose their preferred method of displaying air traffic information for several

variables. Variables included: type of background, update rate, update type, predictor type, and history type. Each pilot designed a display he felt would be most useful in flight operations. After a series of test trials, each pilot was given the opportunity to modify the display for the experimental task. For a second day of testing, they repeated the experimental task using their display as well as displays chosen by other pilots. Results indicated a variety of individual preferences in symbology and differences in the accuracy of judgments. Pilots indicated concern for clutter of the display, relationship of the displayed symbology to physical reality, and a need to perceive the relative motion of the intruder aircraft. Analysis of data indicated that pilots were able to improve their performance with practice.

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#### **Perception of horizontal aircraft separation on a cockpit display of traffic information**

Palmer, E. A. (NASA, Ames Research Center, Man-Vehicle Systems Research Div., Moffett Field, Calif.); Jago, S. J.; Baty, D. L. (San Jose State University, San Jose, Calif.); O'Connor, S. L. National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA. Human Factors, vol. 22, Oct. 1980, p. 605-620. Oct. , 1980

##### **Abstract**

The influence of various display symbologies in a cockpit display of traffic information (CDTI) on pilot perception of horizontal aircraft separation is investigated. In a series of nine experiments using different combinations of display symbology, information update rate, display viewing time and encounter geometry, subjects were asked to predict whether an intruder aircraft would pass in front of or behind their own aircraft. It is found that displayed history did not improve task performance, although it was desired by the pilots when no other display of aircraft turn rate was available, and that pilots made fewer errors when they had predictive information. Variations in the rate of updating information from 0.1 to 4 sec and viewing times from 1 to 16 sec are not observed to affect performance. It is concluded that the present task, which may arise in a collision avoidance situation, would require an onboard computer to make a prediction of relative aircraft position and display it on the CDTI.

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#### **Performance effects of plan-based displays in commercial aviation**

Shalin, Valerie L.; Mikesell, Brian G.; Ramamurthy, Maya (New York, State Univ., Buffalo); Geddes, Norman D. (Applied Systems Intelligence, Inc., Gainesville, GA) In: International Symposium on Aviation Psychology, 7th, Columbus, OH, Apr. 26-29, 1993, Proceedings. Vol. 1 (A95-13001 02-53), Columbus, OH, Ohio State Univ., 1993, p. 138-143. 1993 Contract Number: NAG 1-1342

##### **Abstract**

The experiment reported here examines the performance consequences of alignment between display formats and the methods used during descent. Twelve commercial pilots flew one of nine Standard Terminal Arrival Routes on a stand-alone flight simulator run on a Sparc II workstation. Three different methods for descent (Manual Control, Autopilot, and Spoilers) were crossed with three different displays designed to align with these methods according to scope, resolution, and bandwidth properties in the display of critical information. Performance variability in speed control supports our claim that the effectiveness of a display is not an independent property of the display itself, but rather, a function of the interaction of the display and the particular methods used for achieving task goals

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#### **Perspective and coplanar representation of air traffic - Implications for conflict and weather avoidance**

Merwin, David H.; O'Brien, Janelle V.; Wickens, Christopher D. (Illinois, Univ., Savoy) In: International Symposium on Aviation Psychology, 9th, Columbus, OH, Apr. 27-May 1, 1997, Proceedings. Vol. 1 (A98-28868 07-53), Columbus, OH, Ohio State University, 1997, p. 362-367. 1997 Contract Number: NAG2-996

## **Abstract**

Two experiments compared 2D coplanar with 3D perspective versions of a cockpit display of traffic information. In Experiment 1, 30 certified flight instructors flew a series of traffic conflict detection and avoidance maneuvers around an intruder aircraft, sometimes in the presence of a second intruder. The results revealed an advantage for the coplanar display, particularly when there was vertical intruder behavior. In Experiment 2, 17 instructors flew with the coplanar and perspective formats when weather information was either overlaid or displayed separately. Again, performance was best with the coplanar display, particularly when the weather data were overlaid. The results of both experiments are also discussed in terms of the traffic maneuver stereotypes exhibited by the pilots.

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## **Physiological and subjective evaluation of a new aircraft display**

Wilson, G. F.; Hughes, E.; Hassoun, J. (USAF, Wright-Patterson AFB, OH) IN: Human Factors Society, Annual Meeting, 34th, Orlando, FL, Oct. 8-12, 1990, Proceedings. Vol. 2 (A92-11126 01-54). Santa Monica, CA, Human Factors Society, 1990, p. 1441-1443. 1990

## **Abstract**

Physiological, subjective, and mission effectiveness measures were evaluated to test their relative sensitivity and diagnosticity to pilot workload in a part-mission simulation. Two different radar displays were evaluated in an air-to-air simulated scenario using an advanced horizontal situation format display vs. the conventional radar display. Data were recorded during the ingress and engagement portions of the mission. The engagement segments were associated with higher subjective workload estimates, smaller cardiac IBIs, fewer eye blinks, and shorter duration eye blinks. The new display was associated with shorter duration eye blinks than the current generation display. None of the other measures were associated with statistically significant changes due to display type.

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## **Pilot performance and workload using traffic displays to support Free Flight**

Morphew, M. E.; Wickens, Christopher D. (Illinois, Univ., Urbana) IN: Human Factors and Ergonomics Society 42nd Annual Meeting, Chicago, IL, Oct. 5-9, 1998, Proceedings. Vol. 1 (A99 14126 02-54), Santa Monica, CA, Human Factors and Ergonomics Society, 1998, p. 52-56. 1998 Contract Number: NAG2-996

## **Abstract**

Arising from the need to employ innovative solutions to safely and efficiently maintain air traffic separation in increasingly denser skyways, the concept of Free Flight involves shifting some air traffic management responsibilities from air traffic control specialists on the ground to pilots in the cockpit. Such a shift in traffic management responsibilities will be critically dependent upon the development of displays to provide traffic and hazard information to pilots in the cockpit. This research examined the effect of different information-varying display aids (predictors and threat vectors) for in-cockpit traffic displays, on pilot performance, workload, attentional demands, and flight safety. Fifteen pilots flew a series of traffic avoidance scenarios in a Free Flight simulation designed to assess the effects of different levels of traffic display information on these pilot variables. Three 2D coplanar prototype displays were compared which differed in the level of traffic information provided. Analysis of the data revealed that the traffic display with the most predictive information supported increased safety and decreased workload, without appreciable decrements in flight performance or efficiency.

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**(A) pilot's subjective analysis of a Cockpit Display of Traffic Information (CDTI) (terminal configured vehicle)**

Keyser, G. L., JR. National Aeronautics and Space Administration. Langley Research Center, Hampton, VA. In its The 1980 Aircraft Safety and Operating Probl., Pt. 1 p 29-49 (SEE N81-19035 10-03) Mar. , 1981

**Abstract**

Both the advent of electronic displays for cockpit applications and the availability of high-capacity data transmission systems, linking aircraft with ATC ground computers, offer the opportunity of expanding the pilots' role in the distributive management process. A critical element in this process is believed to be the presentation to the pilot of his traffic situation. A representative cockpit display of traffic information (CDTI) system is presented as viewed from the pilot in the cockpit, and the research results from flight tests presented. The use of advanced controls and displays allows for presentation to the pilot, large quantities of information that he has not had before. The real challenge in the design of an operational CDTI system will be the satisfaction of needs for information and the presentation of all necessary information, only in a useable format in order to avoid clutter. Even though a reasonably large display was utilized in these tests, display clutter was the primary problem from the standpoint of information assimilation.

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**Potential benefits of terminal airspace traffic automation for arrivals**

Ballin, Mark G.; Erzberger, Heinz (NASA, Ames Research Center, Moffett Field, CA) Journal of Guidance, Control, and Dynamics (ISSN 0731-5090), vol. 21, no. 6, Dec. 1998, p. 909-915. Previously cited in issue 09, Accession no. A96-35607. Dec. , 1998

**Abstract**

Advanced air traffic management systems such as the Center/TRACON Automation System should yield a wide range of benefits, including increased airport arrival capacity and reduced aircraft delays. To estimate the traffic flow benefits achievable from future terminal airspace automation, live radar information was used to perform an analysis of current aircraft landing rates and separations at the Dallas/Fort Worth International Airport. Separation statistics that result when controllers balance complex procedural constraints against the need to maintain high landing rates are presented. In addition, the analysis estimates the potential for airport capacity improvements by determining the unused landing opportunities that occur during rush traffic periods. Results suggest a large potential for balancing runway loads and improving the accuracy and consistency of spacing between arrivals on final approach, leading to a potential increase in arrival capacity of at least 15 percent for the Dallas/Fort Worth International Airport and similar airports. This capacity increase may lower operating costs for airport users and substantially reduce the need for future airport expansions.

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**Potential roles for the cockpit traffic display in the evolving ATC system**

Verstynen, H. A. (FAA, Langley Engineering and Development, Field Office, Hampton, Va.) Society of Automotive Engineers, International Air Transportation Meeting, Cincinnati, Ohio, May 20-22, 1980, 15 p. May , 1980 Report Number: SAE PAPER 800736

**Abstract**

The dimensions of the CDTI (Cockpit Display of Traffic Information) concept are discussed with particular reference to aircraft applications and its potential in improving capacity and efficiency in high-density capacity-limited airspaces. Different ways of dealing operationally with CDTI in the cockpit and in the ATC system are examined, and the potential roles that a CDTI might perform in the evolving air traffic control system are discussed.

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### **Predictive techniques for wake vortex avoidance**

Hallock, J. N.; Wood, W. D.; Spitzer, E. A. Transportation Systems Center, Cambridge, MA. In AGARD Plans and Develop. for Air Traffic Systems 11 p (SEE N76-23191 14-04) Feb. , 1976

#### **Abstract**

Aircraft wake vortices represent a major impediment to increasing runway capacity. Separation criteria are conservative most of the time and thus traffic unnecessarily delayed by always adhering to the present inflexible regulations. Systems which employ vortex tracking sensors and/or meteorological sensors to determine safe reduced spacings are being designed. Any wake vortex avoidance strategy relies upon the ability to predict vortex transport and decay. The paper discusses vortex behavior, preliminary predictive models based upon the tracking of vortices from over 24,000 landing aircraft, and systems and their implementation to provide the capability of using adaptive separations.

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### **Reduction of weather-related terminal area delays in the free-flight era**

Johnson, Sally C. (NASA, Langley Research Center, Hampton, VA); Chin, David K.; Rovinsky, Robert B. (FAA, Washington, DC); Kostiuik, Peter F.; Lee, David A.; Hemm, Robert V.; Wingrove, Earl R., III (Logistics Management Inst., McLean, VA). "Reduction of weather-related terminal area delays in the free-flight era." In: AIAA/IEEE Digital Avionics Systems Conference (DASC), 15th, Atlanta, GA, Oct. 27-31, 1996, Proceedings (A96-45660 12-01), Piscataway, NJ, Institute of Electrical and Electronics Engineers, Inc., 1996, p. 185-190. 1996

#### **Abstract**

While much of the emphasis of the free-flight movement has been concentrated on reducing enroute delays, airport capacity is a major bottleneck in the current airspace system, particularly during bad weather. According to the Air Transport Association Air Carrier Delay Reports, ground delays (gate-hold, taxi-in, and taxi-out) comprise 75 percent of the total delays. It is likely that the projected steady growth in traffic will only exacerbate these losses. Preliminary analyses show that implementation of the terminal area technologies and procedures under development in NASA's Terminal Area Productivity program can potentially save the airlines at least \$350 M annually in weather-related delays by the year 2005 at Boston Logan and Detroit airports alone. This paper briefly describes the Terminal Area Productivity program, outlines the cost/benefit analyses that are being conducted in support of the program, and presents some preliminary analysis results.

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### **Requirements for integrated flight and traffic management during final approach**

Sorensen, J. A., Hunter, C. G., and Shen, M. M. (1992). In Proceedings of IEEE Position Location and navigation Symposium, Monterey, CA: Record (A93-10976 01-04).

#### **Abstract**

It is pointed out that significant runway throughput is lost due to ineffective control of aircraft spacing during final approach. The solution is to integrate the terminal air traffic management (ATM) process with cockpit avionics via data link. Components of the ultimate integrated ATM-cockpit design might include (a) an ATM spacing algorithm that accounts for wake vortex and runway occupancy constraints; (b) downlink of desired final approach speed profile; (c) uplink of desired spacing and threshold crossing times; (d) a heads-up traffic display to provide pilot spacing guidance; (e) a flight management system to drive the aircraft to meet timing requirements; and (f) an ATM

display to allow close monitoring of the landing process. The research required to develop this integrated ATM-cockpit concept is presented.

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**Resource document for the design of electronic instrument approach procedure displays (Final Report, Jul. 1993 - Dec. 1994)**

Wright, M. C.; Barlow, T. Battelle Memorial Inst., Columbus, OH. Mar. , 1995, 238P. Note: Sponsored by FAA Report Number: AD-A295108; DOT-VNTSC-FAA-95-9; DOT/FAA/RD-95/2

**Abstract**

Instrument approach procedure (ZAP) charts play a large role in contributing to the success or failure of approaches and landings. Paper ZAP charts have been criticized for excessive clutter, for text sizes that are too small to read, and for inadequate terrain representation. The electronic presentation of approach information may counteract these criticisms by providing automatic or pilot controlled filtering of the information displayed. However, without careful attention to human factors issues early in the design and development of electronic ZAPs (EZAP's), new problems may result. The goal of this project was to develop preliminary guidelines for designers and certifiers of EZAP's to assure that EZAP's help rather than hinder pilots during approach and Landing. To identify potential human factors problems in the design of EZAP's, current paper ZAP charts and the instrument approach task were studied. Pilots were interviewed and literature describing the information requirements of the task and the cognitive implications of thetas were reviewed. A cognitive task analysis was performed. Specific features and functions were identified that may be beneficial to an EZAP. Literature was reviewed in the areas of cognitive psychology, human-computer interaction, and aviation to identify design concepts and principles for the design of these features and functions. Guidelines were developed from the design concepts and principles and, finally, prototypes of EZAP's were designed in accordance with the new guidelines.

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**(The) role of simulation in determining safe aircraft landing separation criteria**

Stuever, R. A.; Stewart, Eric C. (NASA, Langley Research Center, Hampton, VA) National Aeronautics and Space Administration. Langley Research Center, Hampton, VA. Oct. , 1991 , 37P. Presentation Note: FAA, International Wake Vortex Symposium, Washington, Oct. 29-31, 1991, Preprint

**Abstract**

The role of flight simulation in determining safe aircraft landing separation criteria is reviewed and discussed. A broad conclusion is made that previous vortex-encounter simulations were useful for predicting the general response of an aircraft in the presence of trailing vortices and the type of separation criteria to emphasize. These simulations, however, were generally limited in scope and validation. Broad requirements for an accepted simulation methodology are presented. Key technological issues are addressed, including the addition of high-fidelity vortex models and aircraft/vortex interaction effects in the simulation, and validation of simulations with experimental data. Finally, results from a preliminary one-degree-of-freedom simulation are shown. These indicate that reduced landing spacings may be feasible and that current aircraft categorizations should be reviewed.

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**Self-separation in terminal areas using CDTI**

Williams, D. H. (1983). In Proceedings of the 27<sup>th</sup> Human Factors Society. Norfolk, VA: Human Factors and Ergonomics Society.

## Abstract

The Langley Research Center is participating in a joint NASA/FAA program designed to explore the potential benefits and liabilities of Cockpit Display of Traffic Information (CDTI) for a broad range of applications. As a part of this effort, part-task piloted simulations have been conducted to determine the effects of various display parameters and separation criteria on terminal area in-trail following using CDTI. Current experiments are evaluating cockpit procedures and crew workload aspects of self-separation tasks in a simulated full-system terminal area environment. This paper will summarize the results of the part-task terminal area experiments and discuss the current full-system simulation experiments involving active self-separation tasks.

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## Separation monitoring with four types of predictors on a cockpit display of traffic information

Jago, S., and Palmer, E. (1982). In Proceedings of 16th Annual Conference on Manual Control. SEE Paper N82-34037 24-54).

## Abstract

A clear and concise display format for use in later full mission simulator evaluation of the cockpit display of traffic information (CDTI) concept was studied. This experiment required airline pilots to monitor a CDTI and make perceptual judgments concerning the future position of a single intruder aircraft in relationship to their own aircraft (ownship). The main experimental variable was the type of predictor used to display future position of each aircraft. Predictors were referenced to the ground or to ownship and they either included turn rate information or did not. Other variables were the aircraft's separation distance when the judgment was required and the type of encounter (straight or turning). Results indicate that under these experimental conditions fewer errors were made when the predictor included turn rate information. There was little difference in overall error rate for the curved ground referenced and the ownship referenced predictors.

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## Simulation fidelity and numerosity effects in CDTI experimentation (Final Report)

Kreifeldt, J. G. Tufts Univ., Medford, MA. Dept. of Engineering Design. Jan. , 1983 , 10P. Report Number: NASA-CR-166459; NAS 1.26:166459 Contract Number: NCC2-93; RTOP 505 35-21

## Abstract

Twenty pilot workload assessment techniques were compared using a simulated flying task in which three levels of psychomotor workload were imposed. The experiment was conducted in a three degree of freedom motion base simulator. Opinion measures, spare mental capacity measures, physiological measures, eye movement behavior and primary task performance measures were evaluated. The primary task was an instrument landing system (ILS) approach and landing. All measures were recorded between the outer and middle markers on the approach. Three levels of psychomotor load were obtained by the combined manipulation of wind gust disturbance level and simulated aircraft pitch stability. Six instrument rated general aviation pilots participated in the experiment. Cooper-Harper ratings, WCI/TE ratings, time estimation standard deviation, pulse rate mean, and control movements per unit time demonstrated sensitivity to psychomotor load. No intrusion into primary task performance was found that the sensitivities of workload estimation techniques vary widely, and that only a few techniques appear to be sensitive to psychomotor load.

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### **(A) simulation investigation of cockpit display of traffic during curved, descending, decelerating approaches**

Steinmetz, G. (1979). NASA Technical Memorandum 80098, National Aeronautics and Space Administration.

#### **Abstract**

This report presents the results of a simulation experiment involving the evaluation of cockpit display of aircraft traffic information. The experiment was conducted using taped time dependent, non-interactive traffic in an approach or landing situation and two levels of pilot control modes: 3-D automatic and computer augmented control. The tests involved two cases: the simulation aircraft flew approach paths which (a) followed another aircraft in between two other aircraft and (b) merged between two other aircraft. Speed control via manual throttles was used in all tests (path stretching was not allowed for maintaining separation between aircraft). The approaches were conducted while the simulation aircraft was conducting a curved, descending, decelerating approach to landing. Performance data sets were examined and subjective opinions regarding workload were gathered. Traffic positioning was varied to further evaluate the test subjects' monitoring performance.

The results indicate that reasonable approach task performance can be maintained when traffic information is displayed on an RNAV-type map for both merge and follow type situations. Measurable differences in mean and standard deviations of speed profile performance were determined for the inclusion of traffic positions into the display. Cognizance of traffic separation was established within the tests involving traffic and a trend toward reducing separation where large gaps existed was noted. Level of control mode effects produced mixed results. Subjective data indicated a sensitivity to control mode levels. Overall, the results are favorable toward presentation of traffic information during fixed path, curved, descending, decelerating approaches.

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### **(A) simulation model for aircraft sequencing in the near terminal area**

Andreussi, A.; Bianco, L.; Ricciardelli, S. (CNR, Centro di Studio dei Sistemi di Controllo e Calcolo Automatici, Rome, Italy) In: A link between science and applications of automatic control; Proceedings of the Seventh Triennial World Congress, Helsinki, Finland, June 12-16, 1978. Volume 2. (A80-14794 03-63) Oxford and New York, Pergamon Press, 1979, p. 1551-1558. 1979

#### **Abstract**

The paper develops a simulation model to assist in aircraft sequencing operations in the near terminal area. The main characteristics of the model are defined and the general structure of a terminal area with a variable number of feeded fixes and alternative paths from the fixes to the runways, is considered. The model is designed so as to evaluate different operating policies, and a discrete events simulation philosophy using Fortran is employed. A model application to the Rome terminal area is illustrated. It is concluded that the results obtained show that the model is general enough to simulate the terminal area behavior of any airport.

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### **Simulation of a cockpit display concept for increased airport capacity**

Abbott, T. S. (NASA, Langley Research Center, Hampton, VA) National Aeronautics and Space Administration. Langley Research Center, Hampton, VA. IN: Human Factors Society, Annual Meeting, 27th, Norfolk, VA, October 10-14, 1983, Proceedings. Volume 2 (A84-19276 06 54). Santa Monica, CA, Human Factors Society, 1983, p. 777-781. 1983

## **Abstract**

A research effort has been undertaken to determine the feasibility of employing a forward-looking cockpit display to provide information that would enable aircraft to utilize reduced separation, and hence increased runway capacity, through the application of multiple-glide-path approach techniques. The current study was an initial exploration into this concept in which traffic information was added to a HUD format to allow the pilot to monitor the traffic situation and to self space on a lead aircraft during a simulated single glide-path approach. The results of this study indicate that this display concept can provide sufficient information to the pilot for traffic monitoring and self separation. Additionally, the pilots noted that an increase in situational awareness, relative to conventional instrument flight, was provided by the traffic information on the display.

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## **Simulation of automated approach procedures considering dynamic flight operations**

Fricke, M.; Hoermann, A. Technische Univ., Brunswick (Germany). Inst. of Aeronautics and Astronautics. In AGARD, Aircraft Trajectories: Computation, Prediction, Control, Volume 2: Air Traffic Handling and Ground-Based Guidance of Aircraft. Part 4: Air Traffic Handling. Part 5: Guidance of Aircraft in a Time-Based Constrained Environment. Surveillance. Part 7: Meteorological Forecasts. Part 8: Aircraft Operation in Air Traffic Handling Simulation 16 p (SEE N91-10981 02-05) May , 1990

## **Abstract**

During peak hours almost all major commercial airports operate close to their capacity limits. Moreover, the traffic demand often exceeds the offered capacities leading to more or less stringent restrictions in slot allocation. The purpose of the fast-time air traffic simulations, was to analyze and assess the performance and the practicability of automated time-based approach concepts, currently developed to optimize the terminal area air traffic process with respect to safety, capacity and economy. The developed program system TASIMD (Terminal Area SIMulation considering the aircraft Dynamics) simulates flight operations of arriving aircraft within a terminal area during a specific time interval. TASIMD models all major elements of a TMA scenario related to the control and operations of automated approach procedures on the ground and in the air (e.g., surveillance, control procedures, aircraft dynamics, flight guidance). The aircraft fly along 4D-trajectories, described by a horizontal profile, an altitude profile and a speed profile to integrate the time element, considering influences on the path following accuracy in space and time. Sources of error impact are: entry fix time deviation, navigation, wind, airspeed error and profile management algorithm error. Errors are modeled in Monte-Carlo technique. Two types of automated approach procedures were developed and analyzed: a variable path speed control concept (VPSC) and a fixed path speed control concept (FPSC). Both concepts presume a shared air/ground responsibility for profile control.

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## **Simultaneous design of cockpit display of traffic information and air traffic management procedures**

Pritchett, A. (1998). In Proceedings of AIAA/IEEE/SAE Digital Avionics Systems Conference, Bellevue, WA. Vol. 1 Record (A99-28776 07-01) p E36-1 to E36-9.

## **Abstract**

This paper examines two general considerations for designers of CDTI: the information required for intended applications, and the mechanisms capable of providing the pilot with that information. Methods for defining information requirements are summarized, and a case study using control theory analysis is given. The information available from procedures and from CDTI are compared. Suggestions are given for the design of CDTI and air traffic procedures.

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### **Task-oriented display design: Concept and example**

Abbott, T. S. National Aeronautics and Space Administration. Langley Research Center, Hampton, VA. Dec. , 1989, 119P. Report Number: NASA-TM-101685; NAS 1.15:101685  
Contract Number: RTOP 505-67-01-02

#### **Abstract**

The general topic was in the area of display design alternatives for improved man-machine performance. The intent was to define and assess a display design concept oriented toward providing this task-oriented information. The major focus of this concept deals with the processing of data into parameters that are more relevant to the task of the human operator. Closely coupled to this concept of relevant information is the form or manner in which this information is actually presented. Conventional forms of presentation are normally a direct representation of the underlying data. By providing information in a form that is more easily assimilated and understood, a reduction in human error and cognitive workload may be obtained. A description of this proposed concept with a design example is provided. The application for the example was an engine display for a generic, twin-engine civil transport aircraft. The product of this concept was evaluated against a functionally similar, traditional display. The results of this evaluation showed that a task-oriented approach to design is a viable concept with regard to reducing user error and cognitive workload. The goal of this design process, providing task-oriented information to the user, both in content and form, appears to be a feasible mechanism for increasing the overall performance of a man-machine system.

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### **Technology to increase airport capacity**

Harris, R. M. (Mitre Corp., Metrek Div., McLean, Va.) American Institute of Aeronautics and Astronautics, International Meeting and Technical Display on Global Technology 2000, Baltimore, Md., May 6-8, 1980, 6 p. U.S. Department of Transportation May , 1980 Report Number: AIAA PAPER 80-0920 Contract Number: DOT-FA80WA-4370

#### **Abstract**

Technological approaches and operational procedures currently under development by the FAA to increase airport capacities and efficiencies are summarized. Consideration is given to runway configuration management systems, separate short runways for general aviation, dependent IFR runway operations, specialized MLS applications to such areas as missed approach situations, reductions in IFR final approach spacing and integrated flow management. It is concluded that more sophisticated levels of integrated flow management, starting from the current en route metering programs, will be required to obtain maximal terminal flow efficiency and system coordination.

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### **Terminal area forecasts: FY 1989 – 2005**

Henry, T. Federal Aviation Administration, Washington, DC. Forecast Branch. Apr. , 1989 , 527P. Report Number: AD-A209805; FAA-APO-89-5

#### **Abstract**

Forecasts are present for aviation activity of 850 airports in the United States for fiscal years 1989 to 2005. These include 398 airports with FAA air traffic control towers and radar approach control service and 17 FAA contract towers. For each, airport, detailed forecasts are made for the four major users of the air traffic system: air carriers, air taxi/commuters, aviation, and military. Summary tables contain national, FAA regional, and State aviation data and other airport specific highlights. The forecasts have been prepared to meet the budget and planning needs of the constituent units of the FAA headquarters and regional offices and to provide airport-specific information that can be used by State and local aviation authorities, the aviation industry, as a whole, and the general public.

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### **Terminal area forecasts-fiscal years 1993-2010**

Federal Aviation Administration, Washington, DC. Office of Aviation Policy and Plans. Sep., 1994, 557P. Report Number: AD-A290835; FAA-APO-94-11

#### **Abstract**

This report contains forecasts of aviation activity of 875 airports in the United States for fiscal years 1993-2010. These include 401 airports with FAA air traffic control towers and radar approach control services and 29 FAA contract towers. For each airport, detailed forecasts are made for the four major users of the air traffic system: air carriers, air taxi/commuters, general aviation, and military. Summary tables contain national, FAA regional, and State aviation data and other airport specific highlights. The forecasts have been prepared to meet the budget and planning needs of the FAA and to provide airport specific information that can be used by State and local aviation authorities, the aviation industry, and the general public.

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### **Terminal Area Separation Standards: Historical Development, Current Standards, and Processes for Change**

Thompson, S. D. Massachusetts Inst. of Tech., Lexington, MA. Lincoln Lab. Jan. , 1997, 60P. Report Number: AD-A321801; ATC-258; NIPS-97-20967 Contract Number: DTFA01-93-Z 02012

#### **Abstract**

This paper gives an overview and summary of the separation requirements for air traffic control in the U.S. National Airspace System with emphasis on those relevant to terminal landing operations. These requirements are documented in the Federal Aviation Administration's (FAA's) Air Traffic Control Order 711 O.65J, as amended, and various national and local Orders. These requirements are also addressed in the Aeronautical Information Manual, the International Civil Aviation Organization's Standards and Recommended Practices, and the Federal Aviation Regulations (FARs). The purpose of this paper is to assist those people involved with the introduction of new technologies and procedures in the terminal airspace by providing them with an understanding of the separation requirements, the need for those requirements, and the processes used to change the requirements.

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### **Three-D cockpit simulator displays - Achieving precise depth placement of objects in graphic images**

Hasting, John S.; McFarren, Michael J. (USAF, Wright Lab., Wright-Patterson AFB, OH) In: NAECON 94; Proceedings of the IEEE 1994 National Aerospace and Electronics Conference, Dayton, OH, May 23-27, 1994, Vol. 2 (A95-27710 06-66), New York, Institute of Electrical and Electronics Engineers, Inc., 1994, p. 709-714. 1994

#### **Abstract**

The authors have developed software routines to produce 3D images that can be used with any application. Each graphics application tends to have unique features such as the size of objects being drawn or the coordinate system in which these objects are displayed. For example, one application may display objects such as aircraft in a situational display while another displays aircraft system status information. Clearly, coordinate systems and object sizes will differ between these two applications. The stereographic software techniques described are compatible with any coordinate system or size of object and are also compatible with other graphic transformations such as rotation and translation. Stereographic theory is explained in the context of these software procedures as applied in a study of a 3D situational display. Ultimately, the combination of this software and respective explanation will enable any user to develop and display 3D images, reliably placing graphic objects in space.

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### **Three-dimensional displays in the cockpit to improve situational awareness**

Van Breda, Leo; Veltman, Hans A.; Bronkhorst, Adelbert W. (TNO Human Factors Research Inst., Soesterberg, Netherlands) In: Aviation safety: Human factors, system engineering, flight operations, economics, strategies, management; Proceedings of the International Aviation Safety Conference (IASC-97), Rotterdam, Netherlands, Aug. 27-29, 1997 (A98-32251 08-03), Utrecht, Netherlands, VSP, 1997, p. 729-742. 1997

#### **Abstract**

In two flight simulation experiments, the potential benefits of 3D visual (perspective) and auditory radar displays for situational awareness support were investigated. A target localization task was employed in which subjects, flying a fighter aircraft, were required to locate a target that suddenly appeared. Then, a target intercept maneuver had to be performed as quickly as possible. Pilot task performance was determined in terms of target acquisition time and mental workload. Results show that 3D visual information considerably improved task performance, whereas task performance with 3D auditory displays was comparable with a 2D visual display. However, simultaneous presentation of auditory and visual display information clearly improved performance with a 2D visual display; little improvement was found with the 3D visual displays. Implications of 3D visual and auditory displays for pilot support are discussed.

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### **Time-based self-spacing techniques using cockpit display of traffic information during approach to landing in a terminal area vectoring environment**

Williams, D. H. National Aeronautics and Space Administration. Langley Research Center, Hampton, VA. Apr. , 1983 , 43P. Report Number: NASA-TM-84601; L-15520; NAS 1.15:84601 Contract Number: RTOP 505-35-23-03

#### **Abstract**

A simulation study was undertaken to evaluate two time-based self-spacing techniques for in-trail following during terminal-area-approach operations. The tests were conducted in a fixed-base cockpit simulator configured as a current-generation transport aircraft. An electronic traffic display was provided in the weather radarscope location. The self-spacing cues displayed on the electronic traffic display allowed the pilot of the simulated aircraft to follow and to maintain spacing on another aircraft which was being vectored by air traffic control (ATC) for landing in a high-density terminal area environment. Separation performance data and pilot subjective ratings and comments were obtained during the study.

Eight unique approaches representative of the aircraft vectoring used at Stapleton International Airport in Denver, Colorado, were flown and recorded in the simulator for use as target aircraft. The test subjects flew approaches following each of these prerecorded targets using constant-time-predictor and constant-time-delay spacing display formats. These time-based self-spacing techniques provided a spacing distance which was increasingly compressed as both aircraft descended and decelerated during the approach. In addition, the target aircraft left a trail of past-position dots on the electronic traffic display of the pilot's aircraft, which described the horizontal path for the pilot to follow.

Results of the study indicate that the information provided on the traffic display was adequate for the test subjects to accurately follow the approach path of another aircraft without the assistance of ATC. Pilot comments indicate that the workload associated with the self-separation task was high. Location of the traffic display in the weather radarscope position and the sensitive manual control system of the simulator contributed to the high-workload condition. Pilot comments further indicate that additional spacing command information and/or aircraft autopilot functions would be desirable for operational implementation of the self-spacing task.

Analysis of the separation performance data revealed some significant differences between the constant-time-predictor and constant-time-delay spacing techniques. The spacing cue implemented for the constant-time-delay spacing technique produced a significantly lower dispersion in displayed spacing error. Actual spacing accuracy, measured in terms of deviations from ideal spacing, was not significantly different for the two spacing techniques. The constant-time-predictor technique exhibited the inherent problem of requiring the pilot's aircraft to fly an overall slower profile than the lead aircraft. For the particular profiles flown in this study, the constant-time-predictor averaged 10 sec longer than the same runs using constant-time-delay.

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### **Tomorrow's cockpit displays**

Singer, A. C. B.; McClelland, I. W. (Royal Aerospace Establishment, Bedford, England) Aerospace (UK) (ISSN 0305-0831), vol. 18, Nov. 1991, p. 12-14. Nov. , 1991

#### **Abstract**

Research being done to develop the cockpit displays of tomorrow is discussed. The elements of advanced displays are described, and emphasis is given to 4D descent profiles and clearances.

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### **Toward the panoramic cockpit, and 3-D cockpit displays**

Haralson, D. G.; Reising, J. M.; Ghayeb, J. (USAF, Wright Research and Development Center, Wright-Patterson AFB, OH) IN: NAECON 89; Proceedings of the IEEE National Aerospace and Electronics Conference, Dayton, OH, May 22-26, 1989. Volume 1 (A90 30676 12-01). New York, Institute of Electrical and Electronics Engineers, Inc., 1989, p. 80-85. 1989

#### **Abstract**

The authors present ongoing research at the Cockpit Integration Directorate to develop and mature large-area (panoramic) cockpit technology for transition to current and future military aircraft, and to evolve this technology into a three-dimensional (3-D) cockpit display for providing an optimum man-machine interface in future aircraft cockpits. A review of the Panoramic Cockpit Control and Display System (PCCADS) study and final results is presented, and current extensions to that effort are discussed. An assessment of display hardware technology and progress toward realizing a panoramic cockpit display are presented. Finally, related efforts to extend panoramic display technology to 3-D are examined.

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### **Traffic-Watch (cockpit displays for pilots)**

Ramsden, J. M. International Journal of Aviation Safety (ISSN 0264-6803), vol. 1, Sept. 1983, p. 201-206. Sep. , 1983

#### **Abstract**

The feasibility of providing pilots with displays which signal the bearing and proximity of other aircraft is assessed, together with equipment that will be needed to handle a potential doubling of air traffic by the year 2000. A Traffic-Watch display is described that would be fed from a data-link to the ground. All transponder-equipped aircraft would be located and position transmitted to all other commercial aircraft. Monopulse radar interrogators operating in a modified Mode S could furnish the data stream for the displays by activating the identify and altitude

transponder on aircraft. It is noted that the monopulse system can be implemented without altering equipment currently used on commercial aircraft.

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### **Two- and three-dimensional displays for aviation - A theoretical and empirical comparison**

Haskell, Ian D.; Wickens, Christopher D. (Illinois Univ., Savoy) *International Journal of Aviation Psychology* (ISSN 1050-8414), vol. 3, no. 2, 1993, p. 87-109. 1993 Contract Number: NAG2-308

#### **Abstract**

Two displays incorporating prediction and preview for 2D and 3D aviation displays are theoretically and experimentally compared: one display with three orthogonal spatial views and one display with a single 3D inside-out perspective view. The results show that the perspective display fosters superior lateral and altitude flight-path tracking accuracy, while the 2D display fosters superior airspeed tracking accuracy. It is concluded the 3D displays are a viable option for aviation cockpits within the limits of the proximity compatibility principle (PCP) regarding tradeoffs between displays and that human factor designers attempting to apply the PCP to the design of complex displays should be extremely careful when defining tasks. (42 references)

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### **Two effective methods of approach and landing by visual display**

Yokoi, R., and Matsubara, K. (1989). SAE General Aviation Aircraft Meeting and Exposition, Wichita, KS. SAE Paper 891054.

#### **Abstract**

An evaluation is made of the effectiveness of two cockpit visual displays that address the need to improve pilot situational awareness during runway approach and landing operations. The first system considered furnishes a simulated airport runway lighting scheme comparable to night-lighting for visual approaches; the image is projected onto the windscreen by a HUD in all weather conditions. The second system displays the reflector-marked runway contour on the airborne weather radar scope. Both systems are judged to be very effective in facilitating pilot recognition of approach paths.

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### **Who is flying this plane anyway? What mishaps tell us about crew member role assignment and air crew situation awareness**

Jentsch, Florian; Barnett, John; Bowers, Clint A. (Central Florida, Univ., Orlando, FL); Salas, Eduardo (U.S. Navy, Naval Air Warfare Center, Orlando, FL) *Human Factors* (ISSN 0018-7208), vol. 41, no. 1, Mar. 1999, p. 1-14. Mar., 1999

#### **Abstract**

This paper reports a detailed analysis of over 300 civilian incident reports that identified whether loss of situation awareness (SA) was related to air crew role assignment. The results indicate (1) that loss of SA is responsible for an incident more often when the captain is at the controls than when the first officer is at the controls, and (2) that the pilot flying (PF) is more likely to lose situation awareness than the pilot not flying (PNF). As a result, captains lose SA more often across aircraft types, flight segments, and weather conditions when they are the PF than when they are the PNF. The results also suggest that the person who is flying commits more of the critical errors that lead to an incident. Together, the results indicate that captains lose SA more often and make more tactical errors when they are

at the controls than when they are not. Applications of this research include aircrew training, procedure development, and accident/incident analysis.

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# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE April 2001		3. REPORT TYPE AND DATES COVERED Final Contractor Report	
4. TITLE AND SUBTITLE Evaluation of a Terminal Area In-Trail Approach Spacing, Project and Study				5. FUNDING NUMBERS Contract NCC 2-1095	
6. AUTHOR(S) Stephen Shelden					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) San Jose State University Foundation Ames Research Center MS 262-2 Moffett Field CA 94035				8. PERFORMING ORGANIZATION REPORT NUMBER A-00V0042	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington DC 20546-0001				10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA/CR--2001-210920	
11. SUPPLEMENTARY NOTES Point of Contact: Stephen Shelden      San Jose State University Foundation Ames Research Center, MS 262-2, Moffett Field, CA 94035					
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified -- Unlimited Subject Category: 03 Availability: NASA CASI (301) 621-0390				12b. DISTRIBUTION CODE Distribution: Standard	
13. ABSTRACT (Maximum 200 words) Reported here are the results of work completed as a precursor to Distributed Air Ground (DAG), Concept Element 11 (CE11) research. CE11 is a NASA, Advanced Air Transportation Technologies (AATT) concept initiated to promote research on in-trail merging and spacing during approach in the terminal area environment, such that improvements to the National Air Space (NAS) may be realized. A description of the project concept, results of a preliminary study, and a literature review are presented. In terms of conclusions, study results, and reference material respectively: 1) the concept is supported as being significant to NAS capacity improvement, 2) the preliminary study indicated that having more than one downstream, in-trail aircraft present on a CDTI during approach may be advantageous, and that flying traditional Standard Terminal Arrival Routes (STAR) utilizing advanced decision support tools (DST) may be complicated by wake turbulence considerations, a lack of vertical awareness on the part of the flight crew, and the 'step-down' nature of many terminal area approaches, and 3) the results of a literature review are presented for future reference.					
14. SUBJECT TERMS In-Trail Spacing; CDTI				15. NUMBER OF PAGES 71	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT		



